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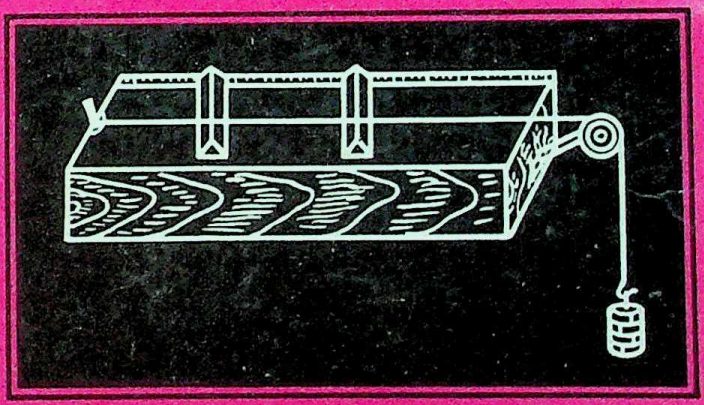
Gandhi Memorial College Of Education Bantalab Jammu

Practical PHYSICS

VOL. I



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CC-0. Jammu Kashmir Digital Preservation Foundation,Chandigarh. Funding by IKS-MoE-2020-Grant

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[STRICTLY ACCORDING TO THE NEW SYLLABUS PRESCRIBED BY THE CENTRAL BOARD OF SECONDARY EDUCATION, NEW DELHI, IN PRACTICAL PHYSICS FOR CLASS XI]

+2 PRACTICAL PHYSICS

Volume I for Class XI

(Containing Experiments, Activities and Investigatory Projects)

By

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PITAMBAR PUBLISHING COMPANY PVT. LTD.

EDUCATIONAL PUBLISHERS

888, EAST PARK ROAD, KAROL BAGH,

NEW DELHI-110005. (INDIA)

CC-0 Agamnigam Digital Preservation Foundation,Chandigarh.Funding by IKS-MoE-2025-Grant

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Published by
PITAMBAR PUBLISHING COMPANY PVT. LTD.
Educational Publishers
888, East Park Road, Karol Bagh,
New Delhi-110 005. (INDIA)
Telephone : Office : 7525528, 7770067, 522997
Resi. : 5737437, 5721321, 5747161
Fax : 91-11-7776058

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First Edition : 1989
Second Edition : 1989
Reprinted : 1990, 1991, 1992
Third Revised Edition : 1993

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Price : Rs. 37/50

Code No. : 27211

ISBN : 81-209-0214-9

Typesetting by
RADHA LASERKRAFT
R-814, New Rajinder Nagar
New Delhi-110060

Printed at :
Piyush Printers Publishers Pvt. Ltd.
G-12, Udyog Nagar
Rohtak Road Industrial Area
New Delhi - 110041
(Tel. : 5472440)

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PREFACE TO THE THIRD EDITION

In this edition the experiments have been revised and regrouped to take account of the modernising of the Physics Practical syllabus for Senior Education. Experiments have been omitted which are now no longer required under the new syllabus.

A section of **activities** (*short experiments*) has been added. These activities intend to make learning of physics more interesting, motivating, effective and meaningful as it involves learning by doing and experimentation. It is hoped that these activities would provide plenty of opportunities for independent thinking, questioning, reasoning and problem-solving in the field of physics. These activities would also help in developing self-confidence, curiosity, initiative, inventiveness and skills of innovation to solve problems.

The effectiveness of the *investigatory projects* demands more involvement of the teacher in planning, foresight, reading and skill. The success of the investigatory project is primarily determined by the extent to which a student involves himself/herself in the whole investigation process. The essential feature of +2 PRACTICAL PHYSICS is the emphasis on the project work which has been included in the new syllabuses for 1993 & 1994 with a view to *encourage experimentation*. It is hoped that +2 PRACTICAL PHYSICS would help pupils to discover the methods of science and provide real thrill, excitement and joyous experience in the learning of physics.

The warm and enthusiastic response to the first edition and to subsequent reprints of +2 PRACTICAL PHYSICS has been a great source of encouragement and inspiration for me to revise it thoroughly in this edition. I earnestly hope that this edition based on the new syllabus (for 1993 & 1994 prescribed by C.B.S.E.) would prove effective and more useful to the pupils.

Furthermore it is hoped that this new edition of the book would help in developing practical skills among pupils. Desired mastery of skills when developed would not only reinforce leaning of scientific concepts and principles but also lead to the development of scientific attitudes and wholesome interest in science. It is expected that physics teachers would find this book more interesting, satisfactory and useful.

I would like to pay my tribute to the work done by my own students—particularly in Air Force Bal Bharti School, Lodhi Road, New Delhi, who have been very patient with me when I have used them as "guinea pigs". **THEY AND MANY OTHER STUDENTS FROM ALL PARTS OF INDIA** have been a fertile source of ideas of which many are included in this edition.

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I am also thankful to hundreds of my valuable friends and fellow teachers from Public Schools, Kendriya Vidyalayas (Central Schools) ; Navodaya Schools ; Government Schools and Government Aided Schools for their valuable suggestions and criticisms for the book. Shortcomings and suggestions for the improvement of the book are always welcome.

My special appreciation and thanks are to the publishers M/s Pitambar Publishing Company P. Ltd. for bringing out the book in the present nice form.

K.K. MOHINDROO

PREFACE TO THE FIRST EDITION

"Experiment is the interpreter of nature. Experiment never deceives, It is our judgement which sometimes deceives itself, because it expects results which experiment refuses." —*Leonardo da Vinci*

We are living in a modern age. A complete and generous education is a prime necessity now, when the competition for existence is growing every moment and the struggle for international supremacy is threatening the very civilization.

We are moving fast, in fact too fast. While the modern inventions have made our actions responsive to touch, the man of tomorrow must know how to keep pace with them. The future man is being manufactured in our class-rooms and laboratories now. To keep pace with his future environments, he must develop in him the technique of maximum output with the minimum of time, energy and material. The present day education ought to help him to acquire that. '*Plus Two Practical Physics*' as a part of education, has a primary duty in this direction.

This book presents a text on Practical Physics intended to meet the need of Class XI students opting for new Physics courses at the Plus Two stage of 10 + 2 year pattern of education. The book has been written after a long and direct contact of 30 years with the students of Physics. In this period of contact I had the privilege to come across the actual problems confronting students in the laboratories.

The broad objectives of the new practical course are :

(1) to develop curiosity of the students.

(2) to learn scientific method and develop creative ability through experiments and investigations, and

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(3) to emphasize practical work in physics through interesting experiments, both short and long, several of which can be done by using low cost items easily available.

The aim of the book is, however, not to replace the teacher. The teacher in the laboratory can always train a young pupil on proper lines ; the present book is to serve as an aid for this purpose.

The book is written in a simple and lucid language and is strictly according to the new syllabus prescribed by the Central Board of Secondary Education, New Delhi. **In the book, greater emphasis has been laid on the experimental, rather than the theoretical aspect of each experiment.** Of course, the theory and the principle of each experiment essential for its successful performance has been duly described and discussed. While describing the steps of procedure for the experiment logically and systematically, attention has been pointedly drawn to the important precautions to be observed at this stage. The record of observations is an important part of the procedure of the experiment. For this purpose simple and self-explanatory tables have been inserted in some experiments and steps of calculation have been methodically shown. Whatever and whenever possible, graphical methods have been introduced.

Figures of instruments and diagrams required for the experiments have been neatly and accurately drawn. They are mostly sectional, simple and their important components have been labelled. Various vital points for drawing scientifically correct conclusions from the observations of an experiment have been discussed in sufficient detail in the "Introduction".

A special feature of this book is that at the end of every experiment there are specimen **Oral Questions with their Answers** (which are usually asked at the time of Board Practical Examinations) concerning the experiment whereby the student is encouraged to test his grasp of the principles. This has been done with the purpose of leading the student to a better understanding of the experiment as a whole and thus to face the Practical Examination with confidence.

The book fully meets the requirements of the changed syllabus in Practical Physics for Class XI of Senior School Certificate Examination of the Central Board of Secondary Education, New Delhi.

The author wishes to express his special appreciation to the publishers, M/s PITAMBAR PUBLISHING COMPANY (P) LTD. for their good work and painstaking efforts in bringing out this book in a short period of time.

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SYLLABUS IN PHYSICS CLASS XI

One Practical Paper **3 hours** **30 marks** **72 Pds.**

Minimum of 10 experiments (minimum of 5 from each Section A and Section B), minimum 7 activities (a minimum of 3 from each section) and one investigatory project are to be performed by each student.

Two experiments	14 marks (7 marks each)
Record of one Investigatory Project and viva based on project	3 + 3 = 6 marks
Record of experiment and activities	3 + 2 = 5 marks
Viva on experiments and activities	3 + 2 = 5 marks

List of Experiments

Section A

1. (a) To measure the diameter of a small spherical/cylindrical body using a vernier callipers.
   (b) To find the volume of the given metallic rectangular block by measuring its dimensions with a vernier callipers and check-up the result by using a graduated cylinder.
   (c) To determine the internal diameter, depth and volume of a beaker/ calorimeter with a vernier Callipers.
2. To measure diameter of a wire by using a screw-gauge and find its volume.
3. To find the inertial mass of a body with the help of known masses using inertial balance.
4. To find the density of the substance of the given rectangular block using a beam balance.
5. To find the weight of a given body using parallelogram law of vectors.
6. To find the downward force along the inclined plane acting on a trolley/roller on account of gravitational pull of earth and study its relationship with the angle of inclination of inclined plane.
7. To find the acceleration of a body and to study how it depends on the force acting on the body and its mass.
8. To study the relationship between force of dynamic friction and normal reaction and to find the coefficient of friction between a block and a horizontal surface.

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9. To determine the acceleration due to gravity using a simple pendulum.
10. To determine the radius of gyration about the centre of gravity of a metre scale used as a bar pendulum.

Section B

1. To study the variations in volume of a sample of air with its constant temperature and hence find the atmospheric pressure.

   Or

   To study the variations of volume of a sample of air with its pressure at constant temperature using a glass syringe with an improvised scale (*e.g.*, a strip of graph paper).
2. To find the surface tension of water by capillary rise method/drop weight method.
3. To find the pressure of a sample of air at constant volume at different temperatures and to study the relationship between pressure and temperature.
4. To determine the coefficient of viscosity of a given liquid by plotting the graph between terminal velocity and square of radius of spherical body.
5. To determine the young's modulus of the material of a given wire.
6. To find the spring-constant of a helical spring by measuring time period of vertical oscillations of a known load and check the result by measuring its extension by a known force.
7. (a) To find the relation between frequency and length for constant tension and diameter of a stretched string using sonometer.

   Or

   (b) To find the relation between length and tension for constant frequency and diameter of a stretched string using sonometer.

   Or

   (c) To find the relation between length and diameter for constant frequency and tension of a stretched string using sonometer.
8. To compare the frequencies of two tuning forks using the resonance tube and find the end correction.
9. To find the velocity of sound at room temperature using the resonance tube and to calculate its value at 0°C.
10. To study the relationship between temperature of a body and time as it cools by radiating heat.

List of Activities

Section—A

1. To find the least count of the given stop clock/watch and use it for checking the time period of oscillation of pendulum of length 1 metre.

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2. To find the force of dynamic (sliding) friction for a wooden block moving on rollers on a horizontal plane.
3. To study the conservation of energy of a ball rolling down on inclined plane (using a double inclined track).
4. To study the conservation of energy of a ball rolling down on inclined plane (using a double inclined track).
5. To study the variation in the range of a jet of water by varying the angle of projection.
6. To locate the position of no friction for the junction of three threads when it is in equilibrium under the action of three forces in the parallelogram law of vectors apparatus.

Section—B

1. To measure the air pressure inside a balloon using an open ended water manometer/multipurpose mercury barometer.
2. To find the atmospheric pressure using Fortin's barometer and to calculate its value in SI Unit.
3. To study the bending of a bi-metallic strip on heating and find out which of the two metals has larger linear expansion.
4. To study the real and apparent expansions of liquids.
5. To determine the spring constant of a spring.
6. To study the variations in length of a rubber band with applied force.
7. To find the frequencies of two tuning forks by counting their beats and identifying the one of higher frequency.

Investigatory Projects

1. To study the changes in velocity of a body pulled by a constant force.
2. To study the conservation of energy of a simple pendulum using ticker-timer and tape.
3. To study the conservation of energy of a body falling freely, using ticker-timer and tape.
4. To study the acceleration due to gravity with the help of ball rolling down an inclined plane and by applying the correction for rotatory motion.
5. To study the acceleration of freely falling body using a ticker-time and a tape.
6. To study the first law of motion by Galileo experiment using the double inclined track *i.e.*, a pair of inclined tracks each of which can be independently set at a small angle in inclination by plotting a

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graph between it's sine (*i.e.*, perpendicular/hypotenuse) and the distance of ascent.

7. To estimate the size of a molecule of an oil.
8. To study the comparative cleansing effect of the different detergents through the study of surface tension.
9. To study the factors upon which the time period of a simple pendulum depends.
10. To study the factors affecting the force of friction (static and kinetic) between two surfaces.
11. To study the factors affecting rate of loss of heat (or rate of cooling) of liquid.
12. To study the effect of surface on emission and absorption of radiation.
13. To study the factors affecting the refractive index of a substance.
14. To study the factors affecting resonant lengths of closed pipes.
15. To study thermocouple and the variation of thermo-emf with temperature.
16. To study the variations in the intensity of a source of light with distance.

Note. These are only specimens of Investigatory Projects. In order to promote innovativeness the students be encouraged to take up new projects (other than the ones mentioned above) in consultation and with the approval of the concerned teacher.

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CONTENTS

Introduction
(Accuracy, Errors, Graphs and Units) (*i*) to (*xviii*)

EXPERIMENTS

SECTION A

Experiment 1 2

(*a*) To find the least count of a vernier callipers.

(*b*) To find the internal and external diameters and depth of a cylindrical body (say a calorimeter) with the help of a vernier callipers.

(*c*) To calculate the internal volume of a cylindrical body (say a calorimeter) and confirm the same using a graduated cylinder.

Experiment 2 11

To find the volume of the given metallic rectangular block by measuring its dimensions with a vernier callipers and check up the result by using a graduated cylinder.

Experiment 3 13

(*a*) To find the least count of a screw gauge.

(*b*) To measure the diameter of a given wire by using screw gauge and compare it by wrapping the same wire around a pencil and explain the difference.

(*c*) To find the volume of the given wire by using screw gauge.

(*d*) To find the gauge of the wire using standard table.

(*e*) To find the thickness of a given glass strip using screw gauge.

Experiment 4 19

To determine the inertial mass of a body with the help of known masses using inertial balance.

Experiment 5 24

To find the density of a substance of the given rectangular block using a beam balance.

Experiment 6 31

(*a*) To locate the position of no friction for the junction of three threads when it is in equilibrium under the action of three forces in the parallelogram law of vectors apparatus.

(*b*) To find the weight of the given body using the parallelogram law of vectors.

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Experiment 7 37

To find the downward force along the inclined plane acting on a trolley/roller on account of gravitational pull of earth and study its relationship with the angle of inclination of the inclined plane.

Experiment 8 42

To find acceleration of a body and to study how the acceleration of body depends on the force acting on it and the mass of the body.

Experiment 9 52

(*a*)To find the force of dynamic (sliding) friction for a wooden block on a horizontal plane.

(*b*)To find the force of rolling friction for a wooden block moving on rollers on a horizontal plane.

Experiment 10 59

To study the relationship between force of dynamic friction and normal reaction, between a block and a horizontal surface, and hence find the coefficient of friction.

Experiment 11 62

(*a*) To find the time-period of a simple pendulum and hence find the value of *g i.e.*, acceleration due to gravity at a place.

(*b*) Draw a graph between l v/s t and l v/s t^2 and study which is better where l is the length of simple pendulum and t is the time period.

(*c*) To determine the length of the second's pendulum from the graph l v/s t^2.

Experiment 12 72

To plot a graph between the distance of the knife edges from the centre of gravity and the time period of a bar pendulum. From the graph find

(*a*) the acceleration due to gravity at* .....

(*b*) the radius of gyration of the bar about an axis passing through the centre of gravity and perpendicular to its plane.

SECTION B

Experiment 13 83

To study a Fortin's barometer and to measure the atmospheric pressure at a temperature at a place.

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Experiment 14 88

To study the variation in volume of a sample of air with its pressure at constant temperature. Also use the study to find the atmospheric pressure.

OR

To verify Boyle's Law for a gas and use it to find the atmospheric pressure.

Experiment 15 96

To measure surface tension of water by capillary rise method.

Experiment 16 107

To determine the surface tension of a liquid (water) by drop-weight method.

Experiment 17 110

To find the pressure of a sample of air at constant volume at different temperatures and to study the relationship between pressure and temperature of the sample of air at constant volume and hence determine the coefficient of increase of pressure of air at constant volume by Jolly's constant volume air thermometer.

Experiment 18 115

To determine the co-efficient of a given liquid by plotting a graph between terminal velocity and square of radius of spherical body.

Experiment 19 122

To study graphically the stress-strain relationship for a steel wire using Searl's Apparatus and to determine the Young's Modulus for it.

Experiment 20 132

To determine the spring constant of a given spring.

Experiment 21 136

To find the spring constant of a helical spring by measuring time period of vertical oscillations of a known load and check by measuring its extension by a known force.

Experiment 22 141

(*a*) To find the relation between length and tension for constant frequency and diameter of a stretched string using a sonometer.

(*b*) Determine the frequency of a tuning fork.

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Experiment 23 152

To find the relation between frequency and length for constant tension and diameter of a stretched string using a sonometer.

Experiment 24 153

To study the relation between length and diameter for constant frequency and tension of a structured string using a sonometer.

Experiment 25 156

To find the velocity of sound at room temperature using resonance tube and to calculate its value at 0°C.

OR

To determine the wavelength of sound by taking first and second resonance positions using resonance tube and explain the difference, if any and hence determine velocity of sound at room temperature and calculate its value at 0°C. Also find the end correction.

Experiment 26 165

To compare the frequencies of two tuning forks using the resonance tube and find the end correction.

Experiment 27 167

To study the rate of the cooling of molten naphthalene/wax and to draw and interpret graph between temperature and time and hence determine the melting point of naphthalene-wax.

OR

To study the relationship between temperature of a body and time as it cools by radiating heat.

ACTIVITIES

SECTION A

Activity 1 173

Aim : To find the least count of the given stop-clock/watch for checking the the time period of oscillations of varying amplitude of a simple pendulum of length 1 metre.

Activity 2 175

Aim : To find the force of dynamic (sliding) friction for a wooden block on a horizontal plane.

Activity 3 175

Aim : To find the force of the rolling friction for a wooden block moving on rollers on a horizontal plane.

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Activity 4 175
Aim : To study the conservation of energy of a ball rolling down on inclined plane (using a double inclined track).

Activity 5 177
Aim : To study the variation in the range of a jet of water by varying the angle of projection.

Activity 6 180
Aim : To locate the position of no friction for the junction of three threads when it is in equilibrium under the action of three forces in the parallelogram law of vectors apparatus.

SECTION B

Activity 1 181
Aim : To measure the air pressure inside a balloon using an open-ended water manometer/multipurpose mercury barometer.

Activity 2 183
Aim : To find the atmospheric pressure using Fortin's barometer and to calculate the value in S.I. units.

Activity 3 183
Aim : To study the bending of a bimetallic strip on heating (as well as cooling) and find out which of two metals has larger linear expansion.

Activity 4 185
Aim : To study the real and apparent expansions of liquids.

Activity 5 187
Aim : To study the co-efficients of apparent expansion of different liquids.

Activity 6 192
Aim : To determine the spring constant of a given spring.

Activity 7 192
Aim : To study the variation in length of a rubber band with applied force (beyond elastic limit).

Activity 8 196
Aim : To find the difference in the frequencies of two tuning forks by counting their beats and identifying one of the higher frequency.

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INVESTIGATORY PROJECTS

Illustrative List of Investigatory Projects 202

Sample Project 1 203

Aim : To draw the *s-t* graph and *v-t* graph of the motion of hand as one walks using ticker-timer.

Sample Project 2 210

Aim : To study the changes in velocity of a body pulled by a constant force and measure its acceleration.

Sample Project 3 214

Aim : To study the conservation of energy of a simple pendulum using ticker-timer and a tape.

Sample Project 4 218

Aim : To study the conservation of energy of a body falling freely using ticker-timer and tape.

Sample Project 5 221

Aim : To find acceleration due to gravity with the help of a ball rolling down an inclined plane and by applying the correction for rotatory motion.

Sample Project 6 225

Aim : To find the acceleration of a freely falling body using a ticker-time and a tape.

Sample Project 7 227

Aim : (*a*) To estimate the size of a molecule of an oil.
(*b*) To estimate the number of oil molecules in a gram-molecule.

Sample Project 8 232

Aim : To study the first law of motion by Galileo's experiment, using the double inclined track (*i.e.*, a pair of inclined track each of which can be independently set at a small angle of inclination).

Sample Project 9 236

Aim : To determine the comparative cleansing effect of the different detergents through the study of surface tension using capillary tube method.

Sample Project 10 238

Aim : To study the factors affecting rate of loss of heat (or rate of cooling) of a metal.

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Gandhi Memorial College Of Education Bantalab Jammu

APPENDICES

Tables of Physical Constants

Table 1. Densities of Some Common Substances in kg m^{-3} 240

Table 2. Acceleration due to gravity at different places in India along with their Latitude, Longitude and Elevation 240

Table 3. Variation of Atmospheric Temperature and Pressure with Altitude 241

Table 4. Surface Tension of Liquids 242

Table 5. Elastic Properties of Solids 242

Table 6. Velocity of Sound (at 20°C unless otherwise stated) 243

Table 7. Standard Wire Gauge 243

Table 8. Co-efficient of Friction of Common Things 244

Table 9. Co-efficient of Expansion 244

Table 10. Densities of Water at Various Temperatures (in gm/cm^3) 245

Table 11. Boiling Points of Water at Various Barometric Heights 245

Table 12. Vapour Pressure of Water at Various Temperatures 246

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INTRODUCTION

(Accuracy, Errors, Graphs and Units)

"Nature is ever making signs to us ; she is ever whispering to us the beginning of her secrets ; the scientific man must be ever on the watch, ready at once to lay hold of nature's hint, however small ; to listen to her whisper, however low." —*M. Foster*

In the world around us various natural phenomena are constantly occurring. The sun rises and sets causing the succession of day and night. The seasons follow in regular cycles. The weather undergoes constant changes. The stars, ligthning, rainbows and many other things we notice have been the cause of wonder and curiosity to man.

Gifted with an inborn intelligence, man has constantly tried to know the cause of the natural phenomena and the natural changes, which he observes in his life. This enquiry carried on through generations, has led to a considerable amount of knowledge which we call **Science.** It is a Latin word which means 'to know'. In a general way, therefore knowledge of all kind is included in science, but in the ordinary accepted sense, *science is that branch of knowledge which studies nature, its working and its laws.* Knowledge connected with non-living bodies or inert masses which go to make up the world is called the **Physical Science,** but *physics concerns itself with an investigation of matter and energy.*

Experiments. The growth of science has been very rapid in the last three hundred years. In this period, the experimental study of nature has been persued and it has proved extremely fruitful in revealing new knowledge, and as a means of deciding different theories, Galileo (1564–1642) may be called the father of experimental sciences. A process of taking observations under conditions deliberately arranged so as to answer a particular question is called an **experiment.** The object of performing an experiment of Physics in the laboratory is generally either to determine the value of some constant *e.g.*, acceleration due to gravity, value of earth's horizontal field, or to verify some principle, *e.g.*, Boyle's law, laws of refraction. An experiment affords the opportunity to a student to familiarise himself with various instruments about which he reads in theory. It further provides him with a golden chance to learn the habit of systematic observations and methodical procedure and thus train him in *"How to do things, honestly, efficiently and regularly".*

Intelligent work is more important than good results ; students, who try to change their observations simply for getting accurate results, do not work with the true spirit of a scientist.

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Accuracy of Observations

The fact that the accuracy of the final result is determined by the accuracy of the individual measurements and that all the measurements should be taken with upmost care is true but sometimes we may err on the other side, *i.e.*, we may waste time in taking some reading too accurately. It is no use taking one observation to a much higher degree of accuracy than the other observations because it will not make the result more accurate. The accuracy of the result is the same as that of the least accurate observation.

The strength of a chain is known by its weakest link and so a good observer will always look at the weakest spot in his measurements. He would take the quantities one by one as they occurs in the formula and would calculate the % error involved in each measurement with the instruments provided. Those quantities which involve large % error would need his keen attention and he would use, if possible, an instrument of greater precision for their measurement, and thus bringing them to the level of the other measurements.

In an experiment all observations are not equally important and the student should have a good idea of their relative importance so that the accuracy in a particular observation is not unnecessary pushed up. More attention should be paid to most important observations.

For example, consider a wire of correct diameter 1.00 mm. If by mistake it is found as 1.02 mm, the error of observation is 2%. Its correct and observed area of cross-section (πr^2) is 0.786 mm^2 and 0.817 cm^2 respectively and the error in its measurement is 4%. If the radius is raised to 4th power, the error would become 8%. *The % error in the result is as many times greater as is the power to which the quantity is raised. So the quantity having the highest power should be measured with highest precision than the rest.*

Accuracy Ordinarily Expected in a Measuring Instrument

The accuracy of a single observation made with a measuring instrument depends upon the instrument as well as on the skill and care with which the observation is made. Assuming that the instrument is correct and that reasonable care has been taken in carrying out the measurement we may expect that the error of a single observation lies within the limits mentioned below :

Instrument	*Error*
Metre-stick (in mm)	1 mm
Vernier Callipers (Vernier Constant = 0·1 mm)	0·1 mm
Screw Gauge (Least Count = 0·01 mm)	0·01 mm
Spherometer (Least Count = 0·01 mm)	0·005 mm
Physical Balance (Sensitivity 1 mg per small division)	2 mg

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Instrument	*Error*
Physical Balance (method of oscillation)	1 mg
Thermometer (0·5°C division)	0.2°C (Using eye-estimation)
Thermometer (0·1°C division)	0.05°C (Using eye estimation)
Stop watch (1/5 second)	2/5 seconds

The table is meant to give the student a *rough* idea of the limit of accuracy and *should not be taken exact.*

The observations should be recorded with the same degree of accuracy as the measuring instrument permits. For example, in the measurement of the temperature with a half degree thermometer it is foolish to put down the reading correct upto a second place of decimal say 26·69, because the least count of the thermometer is 1/2° and at the most we can estimate upto 1/10th of a degree. Thus with such thermometers the observations of temperature should be recorded only upto the first decimal place.

It is commonly used to denote the reliability of the indication of a measuring instrument, when taking an observation, fraction of the smallest divisions may be estimated and recorded as far as possible. For instance, *a length found to be exact 9 cms should be recorded as 9·0 cm to indicate that nearest mm has been read. Similarly, a temperature reading found to be exactly 25° should be registered as 25·0° to indicate that 10ths have been read and so for the mass if it is 76·5 g, it should be noted as 76.500 g to indicate that correct upto a mg has been weighed.*

You may find that in spite of all your efforts, there may be some difference between your calculated result and the standard value from physical constant tables. Absolute error is the difference between calculated result and the standard value. Remember, it is not the absolute error, but the percentage error which is the ratio of the absolute error to the total magnitude of the quantity multiplied by 100 that determines the accuracy of a measurement. If, for example, a student gets the value of g as 960 instead of 980, he is terrified by this large difference of 20 which is the absolute error, but he feels satisfied when he gets 0·000013 as the coefficient of linear expansion of iron in place of 0·000011. The first result, however, $\frac{20 \times 100}{980}$ is only or 2% approximately low, whereas in the second there is an error of $\frac{\cdot 000002 \times 100}{\cdot 000011} = 18\%$. *If you find that your result does not tally with the standard value, do not cook it by changing your observation or writing fictitious reading or by doing wrong calculations but try to find out the cause of errors and state it in the sources of error.*

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ERRORS

The quantities, which the students generally measure, may be mass, length, time, volume, temperature, current, potential difference, degree etc. In all these cases observation finally reduces to the reading of a scale or noting the coincidence between two marks. As the personal judgement of the observer is employed in estimating the coincidence between two marks or in recording the position of a pointer which is between two marks of a scale, so an error is inevitable. Besides, slight changes in experimental condition (*e.g.*, small changes of temperature, pressure, voltage, etc.) may occur during the experiment and lead to small uncertain errors.

1. **Random Errors.** The errors arising out of small changes in the experimental conditions and the personal judgement of the observer are known as random errors. When random errors are due to entirely to chance, and not due to any personal bias on the part of the observer, they are likely to be positive as well as negative. When an observation gives a higher value than the true one, the error in the observation is said to be positive. *Large random errors due to chance are less likely to occur than the small.* If a large number of observations of the same quantity is made, it is likely that most of them will have small errors, each one of which has as much chance of being positive and negative. *Hence the arithmetic mean of several readings is likely to be closer to the true value than any one of the individual readings.*

Values to be Rejected. Sometimes it happens that one of the observed values differs rather widely from the rest. Should it be included in taking the arithmetic mean ? If the relative difference, when calculated in % is very large, it should be certainly rejected. But unfortunately the difference is not always so pronounced as would justify declaring it 'too large and fit to be rejected'. No golden rule could be laid down to say whether a particular observed value should be rejected or retained in taking the mean. To beginners, the following process based on practice will suit :

"Find the difference between arithmetic mean and each individual reading. Add up these differences, disregarding the signs and take their mean which will represent the *mean error.*"

Let the values of focal length in cm of a lens as obtained by a student be *(i)* 37·2, *(ii)* 37·9, *(iii)* 38·3, *(iv)* 38·1, *(v)* 37·8, *(vi)* 38·0. The arithmetic mean is 37.9. The difference between the mean and the individual values are respectively *(i)* –0·7, *(ii)* 0·0, *(iii)* +0·4, *(iv)* +0·2, *(v)* – 0·1, *(vi)* +0·1. When these are added up disregarding their signs, value is 1·5 and the mean value is 1·5 ÷ 6 = 0·25. This value 0·25 represents the mean error and the student may express his value as 37·9 ± 0·25 cm.

2. **Systematic Errors.** If during an experiment, a factor operates in such a way as to make the observed value always higher or lower than the

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true value, this type of error is said to be systematic *e.g.*, instrument errors (zero error, bench error, etc.), radiation loss or gain in calorimetry, etc.

In the case where the source of systematic error is known, action should be taken to remove it. Thus, the zero error of a reading instrument is checked and the proper correction is applied to the reading. Error due to radiation loss is allowed to occur and then corrected for.

In some cases, the source of systematic error may not be definitely known but its existence is apparent. In such cases, the experiment is repeated under different conditions. If variation of conditions does not change the result, one may set his mind at rest that there is no systematic error.

Arithmetic Mean. When a large number of observations are required, as in the measurement of the diameter of a wire, the readings should be taken all over the length and in various directions, even if most of them happen to be the same. They should all be recorded and their arithmetic mean be taken. For taking a really independent reading in the repetition of an experiment, either, if possible some other part of the scale should be used or the magnitude of the various quantities should be altered and the result be calculated in each case. The mean result must then be found. If in an experiment on simple pendulum l_1, l_2, l_3 be the three widely different lengths and t_1, t_2, t_3 the corresponding time periods, then the *mean is not taken of the three lengths and the three time periods, but l/t^2 is calculated for each observation and the mean is taken of the nearly constant results of l/t^2*. It would be unnecessary to calculate 'g' for each observation and then get the mean value of 'g' for, in each case l/t^2 is to be multiplied by a constant $4\pi^2$.

Sometimes due to an accidental error of observation, a particular result comes out to be exceptionally too high or too low. This should be rejected or its observations, if possible, should be checked again, for it will otherwise mar the whole result. Mean cannot be taken when the different results are very much different from one another. In such cases the experiment should be performed again until the differences are reduced to within the experimental error.

Combination of Errors

(a) **Addition and subtraction.** If two quantities are to be added to or subtracted from each other, the error in the result is not obtained by using the fractional errors. The two errors are added together for both addition and subtraction and the result is expressed as a fracion or percentage of either the sum or the difference of the two quantitites. Thus if the two measured quantities have values $x \pm \delta x$ and $y \pm \delta y$ the value of the sum will be quoted as $x + y \pm (\delta x + \delta y)$, and the value of the difference will be $x - y \pm (\delta x + \delta y)$.

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(*b*) **Multiplication and Division.** If two quantities x and y are multiplied together, the fractional error in the product is the sum of the two fractional errors in the x and y. Let δx, δy be the errors in x and y. Then the error in the product will be in the range :

$$(x \pm \delta x)(y \pm \delta y) - xy = \pm y\,\delta x \pm x\delta y$$

We neglect $\delta x \delta y$ as it is small compared with $y\delta x$, $x\delta y$ etc., then the largest possible error (positive or negative) in xy will be $\pm (y\delta x + x\delta y)$ and the fractional error in xy will be $\pm \left[\left(\frac{\delta x}{x}\right)+\left(\frac{\delta y}{y}\right)\right]$ *i.e.*, the sum of the fractional errors in x and y.

The largest value of the quotient will be $\frac{(x+\delta y)}{(y-\delta y)}$ *i.e.*, an error of $\left[\frac{(x+\delta y)}{(y-\delta y)}-\frac{x}{y}\right]$ or a fractional error of

$$\left[\frac{(x+\delta y)}{(y-\delta y)}-\frac{x}{y}\right]+\frac{x}{y}=\frac{xy+y\delta x-xy+x\delta y}{y(y-\delta y)}\times\frac{y}{x}=\left[\frac{\delta x}{x}+\frac{\delta y}{y}\right]$$

neglecting δy in comparison with y.

The smallest value of the quotient will be $\frac{(x-\delta x)}{(y+\delta y)}$ and a similar calculation shows that the fractional error is now $-\left[\left(\frac{\delta x}{x}\right)+\left(\frac{\delta y}{y}\right)\right]$. Thus the quoted error in $\frac{x}{y}$ will be $\pm\left[\left(\frac{\delta x}{x}\right)+\left(\frac{\delta y}{y}\right)\right]$.

(*c*) **Powers.** It is obvious from the above that, if the same quantity x is multiplied together 'n' times (*i.e.*, x^n is obtained), the fractional error in x^n is 'n' times the fractional error in x. It is not quite so obvious that, if the nth root of x is taken, the fractional error is $1/n$ of the fractional error of x, so we shall prove it using the binomial theorem.

$$\text{Error} = (x+\delta x)^{\frac{1}{n}} - x^{\frac{1}{n}} = x^{\frac{1}{n}}\left(1+\frac{\delta x}{x}\right)^{1/n} - x^{1/n}$$

$$= x^{1/n} + x^{1/n}\,\frac{\delta x}{nx} - x^{1/n} = x^{1/n}\frac{\delta x}{nx}$$

$$\text{Fractional error} = \frac{1}{n}\cdot\frac{\delta x}{x}$$

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(*d*) **Logarithmic Functions.** If the final result contains a logarithmic function, there are two ways of dealing with the error. In the first, the logarithms of the mean value plus and minus the error are found, the difference taken, and this is expressed as a fraction of the log of the mean value. Secondly,

$$y = \log_e x$$

$$\delta y = \frac{\delta x}{x},$$

$$\therefore \quad \frac{\delta y}{y} = \frac{\delta x}{xy} \text{ and so the error can be calculated.}$$

(*e*) **Trigonometrical Functions.** Quite often the final result depends upon the sine or some other trigonometrical function of an angle that has been measured. The fractional error wanted will be that of the function and not of the measured angle. Suppose an angle θ has been measured with an error of $\delta\theta$, and the final result includes the expression sin θ.

$$\text{error in } \sin\theta = \delta(\sin\theta) = \cos\theta\,\delta\theta$$

$$\text{fractional error} = \frac{\delta\theta}{\tan\theta}$$

Now tan θ can have all values from 0 to ∞ so that the fractional error can have all values from infinity to 0.

Suppose the critical angle in a medium is measured as $40° \pm 1°$. What is the fractional error in the value of the refractive index ?

$$\mu = \frac{1}{\sin\theta} = \text{cosec}\,\theta$$

$$\delta\mu = -\cot\theta\,\text{cosec}\,\theta\,\delta\theta$$

$$\frac{\delta\mu}{\mu} = -\cot\theta\,\delta\theta$$

$$\cot 40° = 1{\cdot}19,\ \delta\theta = 1° = \frac{\pi}{180} = \frac{1}{60}$$

$$\therefore \quad \frac{\delta\mu}{\mu} = \frac{1{\cdot}19}{60} = \frac{1}{50}$$

$$\mu = \text{cosec } 40° = 1.55 \text{ to 1 part in 50}$$

$$= 1{\cdot}55 \pm 0.03$$

Suppose $y = \tan x$

$$\delta y = \sec^2 x\,\delta x$$

$$\frac{\delta y}{y} = \frac{1}{\cos x \sin x}\,\delta x = \frac{2\delta x}{\sin 2x}$$

This is obviously smallest when sin $2x$ is greatest, *i.e.*, $x = 45°$. If it is possible to choose, one chooses, angles close to 45°.

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Examples on the Calculation of Errors

Example 1. The following observations were actually made during an experiment to find the value of 'g' using simple pendulum.

Length of simple pendulum = l = 100 cm

Time for 20 vibrations = 40 s

Now $$T = 2\pi\sqrt{\frac{l}{g}}$$ when T = time period

l = length of the simple pendulum

g = acceleration due to gravity

$$\therefore \quad g = 4\pi^2 \frac{l}{T^2} = 4\pi^2 \frac{l}{\left(\frac{t}{20}\right)^2}$$

where t = time for 20 vibrations.

or $$g = 4\pi^2 l \cdot \frac{(20)^2}{t^2}.$$

Taking log of both sides

$$\log g = \log 4 + 2\log \pi + \log l + 2\log 20 - 2\log t$$

Differentiating, we have

$$\frac{\delta g}{g} = 0 + 0 + \frac{\delta l}{l} + 0 - \frac{2\delta t}{t}.$$

Converting the negative errors into positive ones for maximum effect, we have

$$\frac{\delta g}{g} = \frac{\delta l}{l} + \frac{2\delta t}{t}$$

$$\therefore \quad \frac{\delta g}{g} = \frac{0{\cdot}1}{100} + \frac{2\times 0{\cdot}1}{40}$$ as δl = 0.1 cm = least count of metre scale

and δt = 0.10 = least count of stop watch.

$$\therefore \quad \frac{\delta g}{g} = 0{\cdot}001 + 0{\cdot}0050 = 0.0060$$

$\therefore$ Maximum possible error = $0.0060 \times 100 = 0.60\%$

As maximum contribution to total error is 0·5% (*i.e.*, $0{\cdot}005 \times 100$) so 't' should be measured very carefully.

Example 2. The following observations were actually made during an experiment to find the radius of curvature of a concave mirror using a spherometer.

l = 4·4 cm, h = 0·085 cm

Now $$R = \frac{l^2}{6h} + \frac{h}{2}.$$

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Taking log of both sides

$$\log R = 2 \log l - \log 6 - \log h + \log h - \log 2$$

Differentiating both sides

$$\frac{\delta R}{R} = \frac{2\delta l}{l} - 0 - \frac{\delta h}{h} + \frac{\delta h}{h} - 0.$$

Converting the negative errors into positive ones for maximum effect, we have

$$\frac{\delta R}{R} = \frac{2\delta l}{l} + \frac{2\delta h}{h}$$

$$= \frac{2 \times 0 \cdot 1}{4 \cdot 4} + \frac{2 \times 0 \cdot 001}{0 \cdot 085} \text{ as } \delta l = 0 \cdot 1 \text{ cm} = \text{Least count of metre scale.}$$

and $\delta h = 0{\cdot}001$ cm = Least count of spherometer.

$$\therefore \quad \frac{\delta R}{R} = 0{\cdot}045 + 0{\cdot}023 = 0{\cdot}068$$

$\therefore$ Maximum possible error = $0{\cdot}068 \times 100 = 6{\cdot}8\%$

It is important to note that the maximum contribution to total error in the result is due to the individual error *i.e.*, 4·5% in the measurement of distance (l) between the fixed legs of the spherometer. Hence 'l' should be measured most carefully.

GRAPH

A *graph* is a line, straight or curved, showing the relation between two variable quantities (*or* their powers *or* functions) of which one varies as a result of the change in the other. It has, however, a much deeper significance.

Just as no amount of a wordy description of a landscape can convey the same, vivid idea to the mind as a painting or a nice photograph, so also no amount of data however nicely recorded, can give a clearly an idea of the relationship between two variable quantities as a graph. A graph has the same utility to a scientist as a picture for a layman.

In hospitals, regular temperature charts are kept of all patients so that the doctor may at once see how the patient's temperature is rising or falling. This would not be possible if he was given figures of temperatures and time, however, nicely entered in a tabular form. Not only this, these days graphs are widely used in almost all departments. There are graphs showing the increase and decrease of revenue in various government departments. You can also have a graph showing how your income and expenditure varies monthly.

A graph gives not only the relation between two variable quantities, it also enable us :

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1. To determine the value of a quantity not actually observed during the experiment, *e.g.*, the temperature of a patient can be known from the graph for a time when it was not actually taken.

2. To verify certain laws *e.g.*, Boyle's law, it tells us how far we have succeeded in taking our observations correctly, for if we do not obtain the required form of a graph for the given relation, we have obviously done error somewhere. The graph shows the magnitude of the error also.

3. To calibrate certain instruments and to determine their true readings, *e.g.*, ammeter, voltmeter, etc.

How to Plot a Graph. Graphs are generally plotted on a paper ruled in millimetre square. The following are few simple rules that will help a student in plotting a good graph :

1. For drawing a graph, take at least six observations extending over a wide range.

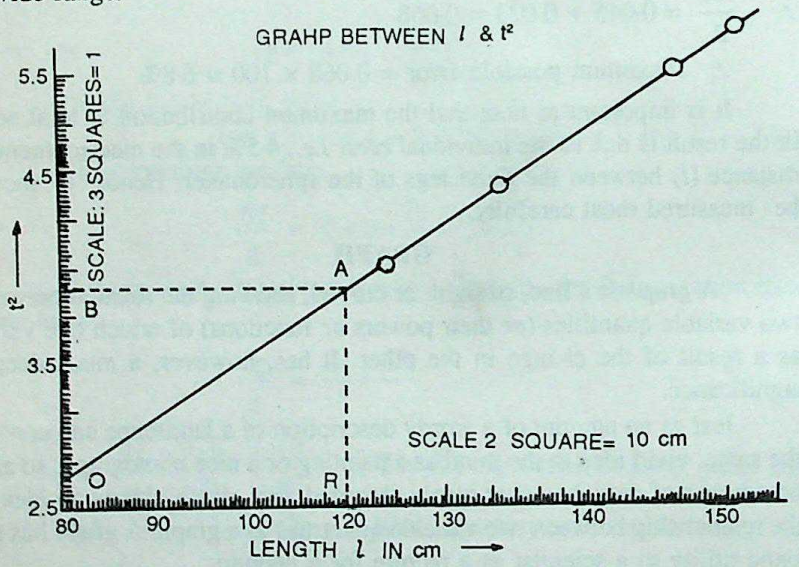

Fig. (i)

2. In case all the observations are positive, draw two thick lines at right angles to each other at the bottom and at the left-hand edge of the paper to indicate the axes of reference, the horizontal line as the *abscissae* or *x-axis* and the vertical lines as the *ordinate* or *y-axis* intersecting at a point O, called the *origin*. If the observations also include some negative quantities, the origin may be taken somewhere in the middle of the paper.

3. As a general rule, the quantity that is made to alter at will is called the *independent variable* and is plotted against the *x*-axis and other which

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varies as a result of, this change is called *dependent variable* and is plotted against *y*-axis. Write clearly under the two axes the quantities which are represented by them.

Examples. (*a*) The relation between natural numbers (*independent variable*) and their squares (*dependent variable*) can be easily represented by a graph.

(*b*) In the simple pendulum where the time period is measured for different lengths by changing the length, *length* is independent variable and the (*time period*)^2 or (t^2) the dependent variable.

(*c*) In the verification of Boyle's Law where the volume is measured for various values of pressure, *pressure* is independent variable and *volume* (or 1/V) the dependent variable.

Sometimes for the sake of convenience, the independent variable is represented along *y*-axis and the dependent variable along *x*-axis *e.g.*, in the case of simple pendulum it is more convenient to take '*l*' along the *y*-axis and *t* or t^2 along the *x*-axis.

4. The scale along each axis should be chosen with a view to utilise the large part of the graph paper and at the same time retaining convenience of plotting. *The unit of length on the graph paper and the unit of the quantities to be plotted should bear, to each other, a simple ratio.* To achieve this, the round number, nearest and slightly less than the minimum value in the data should be taken near the origin and the nearest round number to the maximum value and slightly greater at the end of the required axis, *the successive value being laid along the axis in an ascending order.*

The student need not be disheartened if his points do not fall on the actual line or curve. They are the result of, and in a way a measure of, the amount of unavoidable experimental errors and his honesty.

When is a Straight Line Graph Expected ? The graphs generally drawn in Physics should be straight lines. As the student may judge, by mere look, whether a graph is a straight line where as it is difficult to say whether it forms the part of an ellipse or a parabola. The attempt, therefore, always is to plot graphs between two such quantities as will yield a straight line.

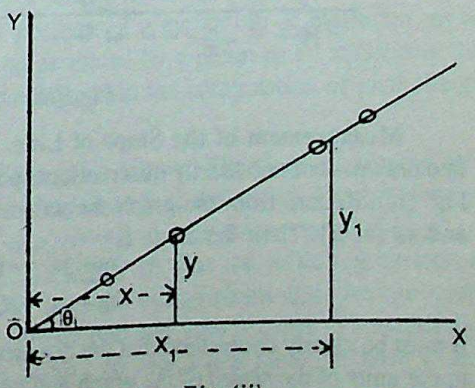

Fig. (ii)

In order to understand when to expect a straight

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line graph, let us study the graph shown in Fig. (*ii*). Here the ratio $y/x = y_1/x_1$ or broadly speaking y/x is constant for every point on the graph and is equal tan θ, where θ is the angle that the graph makes with the x-axis. Thus, whenever the ratio y/x between two variable quantities is constant, one should confidently expect the graph to be a straight line.

As in Boyle's Law PV or xy is constant and not P/V or x/y, the student should put his quantities in the form of x or P and $1/y$ or $1/V$ so that $x \times 1/y$ or $P \times 1/V$ will again be a constant and the resulting graph between P and $1/V$ is a striaght line. It is for this very reason that a graph between length and (time period)^2 is generally plotted in the case of a simple pendulum.

The reader will probably already know that any equation relating two unknown quantities y and x in which no powers higher than the first occur will yield a straight line when y is plotted against x. We can arrange any such linear equation in the form $\boxed{y = mx + c}$ The quantity 'm' is called the gradient or slope of the line. Lines with the same value of 'm' are all parallel Fig. (*iii*). The quantity 'c' is a measure of the distance 'OB' and is called the intercept on the y-axis ; the intercept on the x-axis is $\frac{-c}{m}$. When a straight line graph is used as a source of information we nearly always measure the slope or intercepts or both.

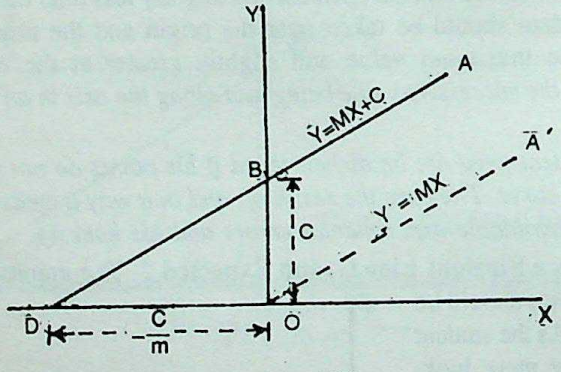

Fig. (iii)

Measurement of the Slope of Line. Select two points A, B on the line drawn—not necessarily observational points—which are well separated Fig. (*iv*). Record from the graph the values of y_A and x_A (at A) and of y_B and x_B (at B). Then the slope is

$$\frac{y_B - y_A}{x_B - x_A} = \frac{BC}{CA}.$$

It must be clearly understood that the distance BC and CA must be measured in the units of the scales of the graph and *not* in centimetres or in 'squares'.

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They are not merely distances *e.g.*, if OY represents volts and OX amperes, the slope would be measured in ohms.

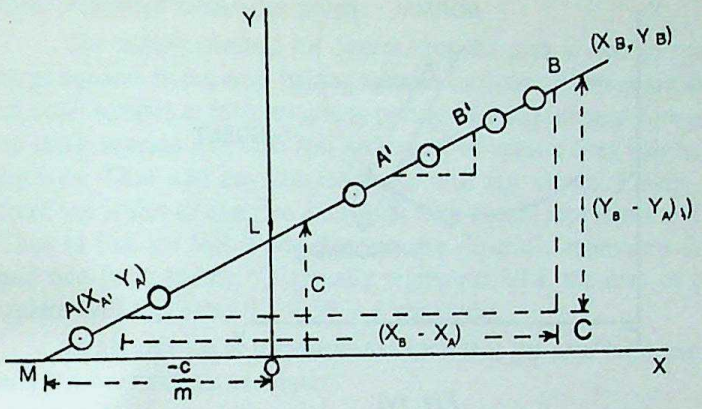

Fig. (iv)

Measurement of Intercepts. If as in Fig. (*iv*), the origin O from which the two scales are measured appears on the paper, it is easy to read off the intercepts OL and OM directly. Sometimes, however, the scale, chosen for quite sound reasons is such that the origin does not appear on the paper. In such instances two well separated points are selected as before and the values of y_A, x_A, y_B, x_B are read from the scales as before. Then $y_A = mx_A + c$ and $y_B = mx_B + c$, so that by solving these equations the values of m, c and $\frac{-c}{m}$ may be found. Alternatively the intercept on one axis can often be read from the graph and then if m is measured, we can calculate the other.

Deductions from curved graphs. Quantitative information is usually derived from curves by measuring the slope of the curve at particular points as in the determination of rate of fall at temperature from a cooling curve, or by determining the position of a maximum or minimum, as in finding the minimum deviation produced by a prism or by measuring the area between the curve and the axis, as in the computation of total charge passed during electrolysis.

Measurement of the Slope of a Curve. The slope of a curve at a given point is the slope of the tangent to it at that point. The problem is, therefore, to draw a tangent to a curve at a particular point P (Fig. *v*). A good method is to place a plane mirror so that the reflecting surface is perpendicular to the curve at P. Turn the mirror about until the curve and its reflection in the mirror appear as one continuous curve. The reflecting surface is then normal to the curve ; so rule a line along its base with a pencil. The tangent is then the line through P at right angles to this normal

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and can be drawn with a set square and its slope can be measured as for any other straight line.

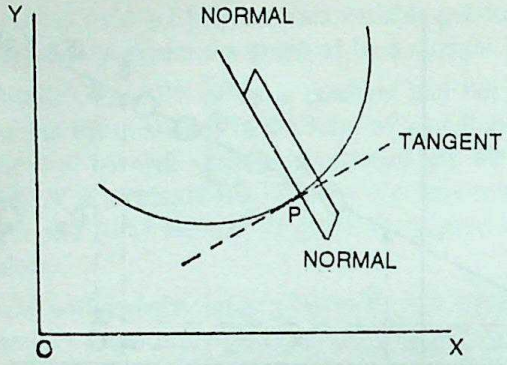

Fig. (v)

Measurement of the Area Under a Curve. It is sometimes necessary to measure the area lying between a curve—or a straight line—and one of the axes. For example, if the current I during an electrolysis experiment is read at regular intervals during its performance and then I is plotted against *t*, the time, a curve of the type shown in Fig. [*vi* (*a*)] may be obtained. The area under the curve *i.e.*, the area lying between the curve and the time axis, will represent the total charge passed in coulombs. For during any small interval '*t*' the current may be considered to have a constant value I and so the area shaded in Fig. [*vi* (*a*)] represents the charge passed during this short-time. Hence the total area lying between the curve and the line OT represents the total quantity of electricity which has passed through the solution. It is probable that the graph may be drawn more as in Fig. [*vi* (*b*)]

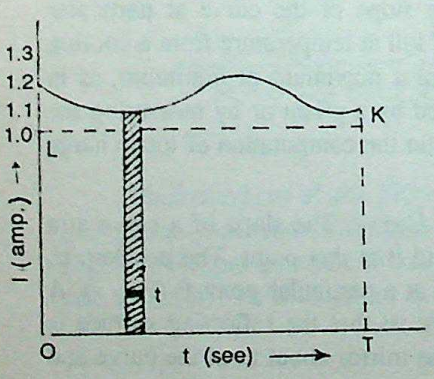

Fig. [vi (a)]

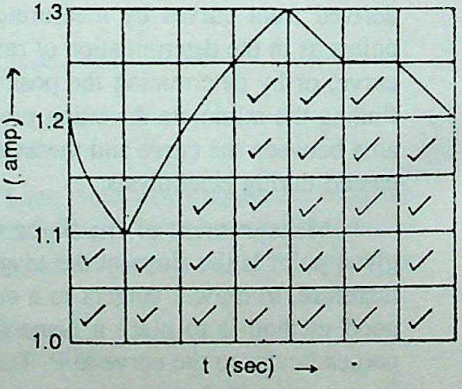

Fig. [vi (b)]

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with true origin not appearing *i.e.*, with the area under the line LK (Fig. *vi* (*a*)] omitted. This will enable the variations in current to be shown on a large-scale. If such is the case remember to add the area under LK to the total computed from your graph.

The easiest method for determining the area is first to count all the large squares in the area, ticking them as recorded. Then count the number of small squares in each remaining portion of a large square. Ignore fractions of small squares less than half and count all greater than half as complete squares. Then add any correction for area not shown. Finally work out from the scales of that two axes what each square represents and multiply. Thus in Fig. [*vi* (*b*)] if one large square vertically represents 0·1 ampere and one large square horizontally represents 30 s, the area of each large square will represent $0{\cdot}1 \times 30 = 3$ coulombs.

In all cases it is important to check that the area between the curve and the correct axis measured.

LOGARITHMS

[Logarithm which literally means "a rule to shorten Arithmetic", "reduces to few days the labour of many months, and so doubles, as it were, the life of a mathematician besides freeing him from the errors and digest inseparable from long calculations."] —*Laplace*

Logarithms were invented by Napier.

"My lord, I have undertaken this journey purposely to see your person, to know by what engine of wit or ingenuity you came first to think of this excellent help in Mathematics, viz., the logarithms. — Briggs to Napier

Definition and Notation. If $a^x = N$; then x is called the *logarithm* of N to the base a, and is denoted by $\log_a N$ (read "log N to the base a").

[In words : The *logarithm of a number to a given base* is the *index* of the power to which the base must be raised to equal that number].

Example. We know that $3^4 = 81$. Therefore 4 is the logarithm of 81 to the base 3, *i.e.*, $\log_3 81 = 4$.

Logarithms are two types : (*i*) *Naperian* in which the base is *e*. They are used in practice. (*ii*) *Common*, in which the base is 10. They are commonly used. When the base is not mentioned, it is implied that the base is 10. Four-figure Logarithm Tables of natural numbers to the base 10 are given at the end of this book.

Common Logarithms

Logarithm of a number consists of two parts :

(1) *Characteristic* is the integral part (whole or natural number).

(2) *Mantissa* is the fractional part generally expressed in decimal form.

Note : The *mantissa* is always positive.

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How to find the characteristic of a number. The characteristic depends on the magnitude of the number and is determined by the position of the decimal point. *For number greater than one, the characteristic is positive and one less than the number of digits to the left of the decimal point. For numbers smaller than one (decimal fraction), it is negative and one more than the number of zeros between the decimal part and first digit.*

Examples : Characteristic of 530800 is 5
5308 is 3
53·38 is 1
5.308 is 0
·5308 is -1
·05308 is -2
·0005308 is -4
·00005308 is -5

The negative characteristic is usually written as $\bar{1}$, $\bar{2}$, $\bar{4}$, $\bar{5}$, etc., and is read as bar 1, bar 2, etc.

How to find the Mantissa of a number. The value of mantissa depends on the *digits* and their *order*, and is independent of the position of the decimal point. As long as the digits and their order is the same the mantissa is the same, whatever be the position of the decimal point.

The logarithm tables give the mantissa only. They are usually meant for number containing four digits, and if a number consists of more than four digits, it is rounded off to four digits 632562 should be taken as 6326 and 632537 as 6325. To find mantissa tables are consulted in the following manner :

1. The first two significant figures of the number are found at the extreme left vertical column of the table wherein the number lying between 10 and 99 are given. The mantissa of the digits which are less than 10 can be determined by multiplying the figures by 10, *i.e.*, the mantissa of 2, 20, 200 and so on, is the same.

2. Along the horizontal line in the topmost column the figures

0	1	2	3	4	5	6	7	8	9	10

are given. They correspond to the third significant figure of the given number.

3. The difference for the fourth significant digit is given further in differences column under

1 2 3	4 5 6	7 8 9

. From 10 to 19 double differences are given. If the third figure is from zero to four the upper line should be read and for the figures from 5 to 9, lower line.

Example 1. *Find the logarithm of 368.6.*

The number has 3 digits to the left of the decimal point. Hence its characteristics is 2.

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To find the mantissa ignore the decimal point and look for 36 in the first vertical column and 8 in the central topmost column. Proceed from 36 along a horizontal line towards the right and from 8 vertically downwards. The two lines meet at a point where the number 5658 is written. This is the mantissa of 368. Proceed further along the horizontal line and look vertically below the figure 6 in the differences column. You will find the figure 7 there. Hence the mantissa of 3686 is 5658 + 7 = ·5665.

∴ The logarithm of 368·6 is 2·5665.

Example 2. *Find the logarithm of 368600.*

The characteristic of this number is 5 and the mantissa is the same as in Example 1.

∴ Logarithm of 368600 is 5·5665.

Example 3. *Find the logarithm of ·00368633.*

The characteristic of this number is $\bar{3}$ as there are two zeros following the decimal point. We can find the mantissa of only 4 significant digits. Hence we neglect the last 2 digits (33) and find the mantissa of 3686 which is ·5665.

∴ Logarithm of ·00368633 is $\bar{3}$·5665.

When the last figure of a number consisting of more than 4 significant digits is equal to or more than 5 the digit next to it is raised by one and so on till we have only 4 significant digit and if the last digit is less than 5 it is neglected as in the last example.

Imp. If we have the number 368658, the last digit is 8, therefore, we shall raise the next digit to 6 and since 6 is again more than 5, we shall raise the next digit to 7 and find the logarithm of 3687.

Antilogarithm. The number whose logarithm is x is called the *antilogarithm* of x, and is denoted by *antilog* x.

Thus, since log 2 = ·3010, antilog ·3010 = 2.

Example 1. *Find the number whose logarithm is 1·6078.*

(*i*) The characteristic = 1. This is one less than the number of digits in the integral part of the required number, hence the number of digits in the integral part of the required number is 1 + 1 = 2.

(*ii*) Removing the integral part 1 from the given logarithm we get ·6078. The *first two digits* from the left are 60, the *third digit is* 7 and *fourth* is 8.

(*iii*) In the table of the antilogarithms, look in the first vertical column for ·60. In this horizontal row under the column headed by 7, we find the number 4046 at the intersection.

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(*iv*) In the continuation of this horizontal row and under the mean differences column on the right headed by 8, we find the number 7 at the intersection. Adding 7 to 4046, we get 4053.

(*v*) Antilog 1·6078 = 2 + ·4053 = 2·4053

Example 2. *Find the antilogarithm of* $\bar{2} \cdot 6078$.

As the characteristic is $\bar{2}$, there should be one zero on the right of decimal in the number. Hence antilog $\bar{2}$·6078 = ·04053.

Laws of Logarithms. From the laws of indices we obtain the following laws of logarithms :

1. $\log_a mn = \log_a m + \log_a n$
2. $\log_a m/n = \log_a m - \log_a n$
3. $\log_a m^n = n \log_a m$

Two important Special Cases

(*i*) $\log_a 1 = 0$ [The logarithm of 1 to any base is zero] as $a^0 = 1$.

(*ii*) $\log_a a = 1$ [The logarithm of the base to itself is 1] as $a^1 = a$.

Example 1. *Volume of a cylinder of length 3·47 cm is 1·932 cm*^{3}. *Determine its radius.*

$$\text{Volume (V)} = \pi r^2 l$$

$$r^2 = \frac{V}{\pi l}$$

$$r = \sqrt{\frac{V}{\pi l}} = \sqrt{\frac{1 \cdot 932}{3 \cdot 142 \times 3 \cdot 47}}$$

$$\log r = 1/2 (\log 1 \cdot 932 - \log 3 \cdot 142 - \log 3 \cdot 47)$$

$$= 1/2 (0 \cdot 2860 - 0 \cdot 4972 - 0 \cdot 5403)$$

$$= -\tfrac{1}{2} \times \cdot 7515 = - \cdot 3758 = \bar{1} \cdot 6242.$$

[**Note.** The mantissa should always be in positive even though the logarithm comes out in negative.]

Taking antilogarithm of $\bar{1}$·6242.

We get r = ·4209 cm

Basic S.I. Units

1. Length—metre (m) 2. Mass—kilogram (kg) 3. Time—second (s) 4. Temperature—kelvin (K) 5. Amount of Substance—mole (mol) 6. Intensity of illumination—candela (cd) 7. Current—ampere (A).

Derived Units

1. Energy—joule (J) 2. Force—newton (N) 3. Area—square metre (m^2) 4. Volume—cubic metre (m^3) 5. Density—kg/m^3 6. Velocity—metre per second (m/s). 7. Acceleration—metre per second^2 (m/s^2). 8. Frequency—hertz (Hz). 9. Resistance—ohm (Ω). 10. Pressure—newton per square metre (N/m^2) 11. Potential difference—volt (V).

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EXPERIMENTS

Minimum of 10 experiments (minimum of 5 from each SECTION A and SECTION B) are to be performed.

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SECTION A

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EXPERIMENT 1

(a) To find the least count of a vernier callipers.

(b) To find the internal and external diameters and depth of a cylindrical body (say a calorimeter) with the help of a vernier callipers.

(c) To calculate the internal volume of a cylindrical body (say a calorimeter) and confirm the same using a graduated cylinder.

Apparatus :

Vernier callipers, calorimeter and a graduated cylinder.

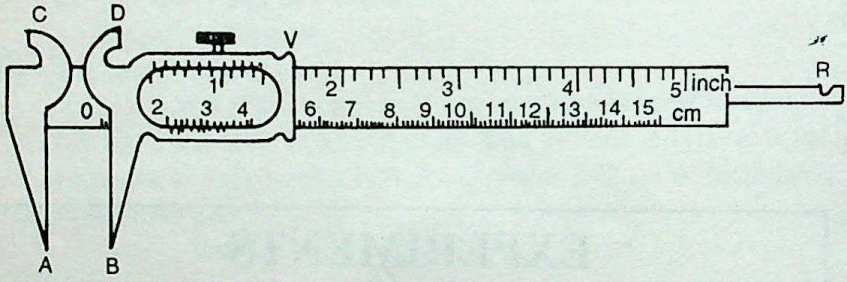

Fig. 1.1. Vernier callipers

Theory :

A very ingenious device for obtaining accuracy of a greater order than that obtainable by eye estimation was invented by P. Vernier (1580—1637) and is known by his name *i.e.*, VERNIER. In this device a small auxiliary scale is provided, which slides along the ordinary scale, the divisions of this *Vernier Scale* being either a little longer or a little shorter than the divisions of the ordinary scale.

The great value of this device lies in its simplicity and in the fact that it can be used to measure to any fraction of a division required, if the auxiliary scale is divided suitably.

The auxiliary scale is graduated from a division which may be called the *zero of the Vernier*, this division being indicated by some distinguishing mark. The scale consists of n equal divisions on one side of the Vernier zero. These n Vernier divisions are exactly equal to $(n-1)$ scale divisions.

Consequently one Vernier division is equal to $\frac{n-1}{n}$ or $\left(1-\frac{1}{n}\right)$ of a scale division. Thus, *each Vernier division is shorter than a scale division by* $\frac{1}{n}$ *of a scale division.* This quantity $\frac{1}{n}$ of a scale division is called the **Least Count (or Vernier Constant) of the Vernier.**

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An instrument called the **Vernier Callipers** is used for measuring the linear dimensions of bodies. It consists of a metal rule furnished with two jaws, A and B (Fig. 1.1) projecting at right angles to the rule. Of these A is fixed whilst the other B can slide backwards and forwards. The upper jaws C and D are used to measure the internal dimensions of the hollow objects. On the rule is engraved a scale divided into millimetres. The sliding jaw B is also provided with a short scale V called a Vernier. The sliding strip or rod R is used to measure the depths of certain objects. It is connected to the Vernier scale and slides with vernier along the main scale.

Now the volume of a cylinder

$$= \pi r^2 \cdot l = \frac{\pi d^2}{4} \cdot l$$

where r = radius of the cylinder, l = length or height of the cylinder
and d = diameter of the cylinder.

Since a given calorimeter possesses a hollow cylindrical shape, so it will have two diameters external and internal and hence two radii.

If V_E is the external volume of the calorimeter, then

$$V_E = \frac{\pi d_1^2}{4} \cdot l_1$$

where d_1 = external diameter of the calorimeter
and l_1 = external length of the calorimeter.

If V_i is the internal volume of the calorimeter, d_2 is the internal diameter of the calorimeter and 'h' is the depth of the calorimeter, then

$$V_i = \frac{\pi d_2^2}{4} \cdot h$$

Procedure :

(*i*) Determine the *least count* (or *vernier constant*), *i.e.*, the distance between the value of one main scale division and one vernier scale division of the vernier callipers as explained in the theory above.

(*ii*) Find the *zero error* by bringing the jaws A and B of the vernier callipers closely in contact. If there is no zero error this fact should be recorded.

The Zero Error :

In some instruments when the movable jaw B is brought in contact with the fixed jaw A, the zero of the vernier scale may not coincide with the zero of the main scale. In this case, the instrument is said to possess zero error which may be *positive* or *negative* according as the zero of the

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vernier scale lies to the right or left to the zero of the main scale and a correction has to be applied to the observed reading in order to determine the correct value.

To find the zero error, suppose the zero of the vernier scale lies to the right of the zero of the main scale, and nth vernier division coincides with any main scale division. The error is obtained by multiplying n with the vernier constant and a positive sign is put before it as the length measured by the instrument is more than the actual length.

If the vernier zero lies to the left of the main scale zero, the coinciding vernier division is to be seen from the other end of the vernier scale and its number multiplied by the vernier constant gives the required zero error with a negative sign placed before it as the length measured by the instrument is less than the actual length.

The zero error is always algebraically subtracted from the observed reading. Sometimes it is preferred to know the zero correction of the instrument. It has a sign opposite to that of the zero error but is equal in magnitude and is always algebraically added to the observed value to obtain a correct one.

(*iii*) To measure **external diameter** of the calorimeter, place it *diameterwise* between the two jaws A and B of the vernier callipers in such a way that it is just held between the jaws without undue pressure. Note the main scale reading which is just *before the zero* of the vernier scale and also find the number of the vernier division which is in line with a main scale division. Multiply this vernier division by the least count or vernier constant and add it to the main scale reading to get the observed external diameter of the calorimeter. The corrected external diameter is calculated by applying zero correction.

Repeat the observations *at least three times* at three different places in *two perpendicular directions*. The mean corrected external diameter (d) is found.

(*iv*) To measure **internal diameter** of the calorimeter, make use of the upper jaws C and D of the vernier callipers. Insert the upper jaws in the calorimeter and adjust the position of the movable jaw D in such a way that C and D touch the inner walls of the calorimeter gently without exerting undue pressure on them. Note the reading of the vernier callipers in the same manner as explained in (*iii*) above and then find the correctred internal diameter after applying zero correction.

Repeat the observations at least *three times* at three different places in *two perpendicular directions*. The mean corrected internal diameter (d_2) is found.

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(*v*) To measure **depth** of the calorimeter, the sliding strip R of the vernier callipers (Fig. 1.1) is used.

Put the edge of the main scale of the vernier callipers on the mouth of the calorimeter (the callipers being held vertically), in such a way that the strip R is able to go inside the calorimeter along its length. Move the sliding jaw so that the strip R touches the bottom of the calorimeter gently.

Read the vernier callipers in the same manner as explained in (*iii*) above which gives the observed depth of the calorimeter. The corrected depth is calculated by applying zero correction.

Repeat the observations at least *three times* and then find the mean corrected depth (h) of the calorimeter.

(*vi*) Calculate the internal volume V_i by using the formula

$$Vi = \frac{\pi d_2^3}{4} \cdot h \text{ cm}^2$$

(*vii*) Verify the internal volume thus calculated with the help of a graduated cylinder *i.e.*, fill the calorimeter upto the brim with water and then pour this water into the graduated glass cylinder and note the volume of water directly in cm^3.

Observations :

Least Count or Vernier Constant (V.C.)

$$n \text{ V.D.} = (n-1) \text{ M.S.D.}$$

where V.D. = Vernier scale division

and M.S.D. = Main scale division

$$\therefore \quad 1 \text{ V.D..} = \frac{(n-1)}{n} \text{ M.S.D.}$$

$$\text{Difference [M.S.D. – V.D.]} = \left[1 - \frac{(n-1)}{n}\right]$$

$$= \frac{1}{n} \text{M.S.D.}$$

But $1 \text{ M.S.D.} = x \text{ mm}$

$$\text{Vernier Constant (V.C.)} = \frac{1}{n} \times x \text{ mm}$$

$$= \frac{x}{10n} \text{cm}$$

For example :

$$10 \text{ V.D.} = 9 \text{ M.S.D.}$$

$$1 \text{ V.D.} = \frac{9}{10} \text{M.S.D.}$$

$$\text{Difference [M.S.D. – V.D.]} = \left(1 - \frac{9}{10}\right) = \frac{1}{10} \text{M.S.D.}$$

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But 1 M.S.D. = 1 mm

$\therefore$ Vernier Constant (V.C.) = $\frac{1}{10} \times 1$ mm

= 0·1 mm = ·01 cm

Zero Error :

(1) ..... cm (2) ..... cm (3) ..... cm

Mean Zero Error = ... cm

Mean Zero Correction = ± ..... cm

External Diameter of the Calorimeter :

S. No.	One direction			Mutually perpendicular direction			Mean observed diameter in cm
	Main scale reading in cm (a)	No. of vernier division coincident (n)	Observed diameter in cm = (a) + n × V.C.	Main scale reading in cm (a)	No. of V.D. coincident (n)	Observed diameter in cm = (a) + n × V.C.	
1.							
2.							
3.							
						Mean = A =	..... cm

Hence mean corrected external diameter = d_1 = A + (zero correction)

= ..... cm

Internal Diameter of the Calorimeter :

S. No.	One direction			Mutually perpendicular direction			Mean observed diameter in cm
	Main scale reading in cm (a)	No. of vernier division coincident (n)	Observed diameter in cm = (a) + n × V.C.	Main scale reading in cm (a)	No. of V.D. coincident (n)	Observed diameter in cm = (a) + n × V.C.	
1.							
2.							
3.							
						Mean = B =	..... cm

Hence mean corrected internal diameter = d_2 = B + (zero correction)

= ..... cm

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Depth of the Calorimeter :

S. No.	Main scale reading in cm (a)	No. of V.D. coincident (n)	Vernier scale reading in cm = $n \times$ V.C.	Observed depth in cm = (a) + $n \times$ V.C.	Mean observed depth in cm
1.					
2.					
3.					

Hence mean corrected depth of the calorimeter

(h) = (Mean observed depth) + (zero correction)

= ..... cm

Calculations :

Internal Volume of the Calorimeter

$$V_i = \frac{\pi d_2^2}{4} \cdot h = \text{.....} \text{cm}^3$$

= ..... m^3

Verification by Graduated Cylinder :

Volume of water filling the calorimeter upto the brim

= ..... cm^3

= ..... m^3

Result :

(i) Least count of the vernier callipers = ... cm

(ii) External diameter of the calorimeter = ... cm

(iii) Internal diameter of the calorimeter = ... cm

(iv) Depth of the given calorimeter = ... cm

(v) Internal volume of the given calorimeter = ... cm^3

= ..... m^3

Precautions :

(i) The zero error should be noted carefully with *sign* and taken into account.

(ii) The jaws should not be *pressed* too hard.

(iii) The dimension to be measured (length, diameter or depth) should be parallel to the main scale.

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(*iv*) The calorimeter should be held between those positions of the jaws which are in *contact* when the callipers is closed without placing the calorimeter between them.

(*v*) The calorimeter between the jaws should not be held either too tight or too loose.

(*vi*) Oil the vernier if its motion is not smooth.

(*vii*) While measuring the depth, the strip should be perpendicular to the bottom surface.

(*viii*) While measuring the depth, the edge of the main scale should not get out of contact from the mouth of the calorimeter when the end of the sliding rod R touches the bottom.

(*ix*) Zero error for the measurement of depth is different from the usual zero error of a vernier callipers. So it should be determined separately and carefully as explained below :

[When the two jaws A and B are made to touch each other, the end of the sliding strip R and the edges of the main scale get in line with each other in a perfect instrument. In a defective instrument, the end of the strip R may not be exactly in line with the edge of the main scale when the instrument reads zero. In such a case, it is said to possess *zero error which is relevant only for depth measurement.* The reading when the end of the sliding strip R lies exactly in line with edge of the main scale, equals the *magnitude* of this zero error].

Sources of Error :

1. Vernier jaws may not be at right angles to the main scale or parallel to each other.
2. None of the vernier divisions may be exactly coincident.
3. The vernier scale may be loose.
4. The graduations on the scales may not be evenly marked.

Exercises

(1) *To find (a) the diameter, (b) the surface area, and (c) the volume of a sphere using vernier callipers.*

Hint : Measure the diameter of the sphere at four different places as in Expt. 1. and calculate its surface area and volume.

Surface area of sphere $= 4\pi r^2$

Volume of sphere $= \frac{4}{3}\pi r^3$

(2) *To determine the internal and external diameter of a calorimeter and to calculate the thickness of its wall. Also find the depth of the calorimeter with the help of vernier callipers.*

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Hint : Measure the external diameter by using the jaws A and B and internal diameter by using the jaws C and D. Difference of the two gives *twice* the thickness of the calorimeter wall.

(3) *To determine the length and diameter of a given cylinder by vernier callipers and hence calculate its volume.*

ORAL QUESTIONS

Q. 1. *What is a vernier callipers ? Why is it called a vernier callipers?*

Ans. It is an instrument used to measure small lengths and diameters accurately. It is called vernier callipers after the name of its inventor "Pierre Vernier".

Q. 2. *What is Least Count ?*

Ans. It is the least distance that can be measured by the instrument.

Q. 3. *Define vernier constant.*

Ans. It is the difference between the smallest division of main scale and that of vernier scale.

Q. 4. *What part of the instrument is the vernier scale ?*

Ans. The small scale that slides along the main scale is called vernier scale.

Q. 5. *What is the difference between Vernier Constant and Least Count ?*

Ans. Practically no difference. Vernier constant is the Least count but is used only for vernier callipers whereas least count is used for all the instruments.

Q. 6. *What is zero error ?*

Ans. The instrument is said to have zero error, if the zero of the main scale does not coincide with the zero of the vernier scale when the two jaws of the vernier callipers are brought into contact.

Q. 7. *When is the zero error positive ? When is the zero error negative ?*

Ans. If the zero of the vernier scale is towards the right of the main scale, the error is said to be positive (Fig. 1.2.). If the zero of the vernier scale is towards the left to the main scale, the error is said to be negative (Fig. 1.3).

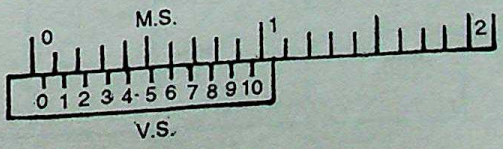

Fig. 1.2. Positive error

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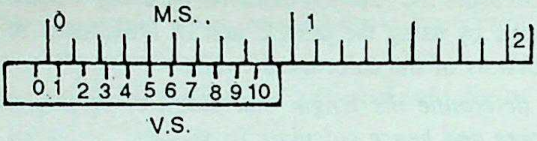

Fig. 1.3. Negative error

Q. 8. *What is zero correction ?*

Ans. It is equal in magnitude but opposite in sign to zero error.

Q. 9. *Why does zero error creep in ?*

Ans. It creeps in because of wear and tear due to the long use of the instrument.

Q. 10. *What is 'angular vernier' ?*

Ans. Angular vernier is used to measure fractions of a degree. These are provided in spectrometers and sextants.

Q. 11. *Which will be more accurate—a calliper of small V.C. or that of large V.C. ?*

Ans. A calliper of small V.C.

Q. 12. *What is the function of the upper jaws of the vernier callipers?*

Ans. To measure the internal dimensions of the hollow objects.

Q. 13. *What is the function of the sliding strip or rod ?*

Ans. To measure the depths of certain objects.

□□

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EXPERIMENT 2

To find the volume of the given metallic rectangular block by measuring its dimensions with a vernier callipers and check up the result by using a graduated cylinder.

Apparatus :

Metallic block ; vernier callipers ; graduated cylinder.

Procedure :

Measure the length, breadth and thickness of a given metallic rectangular block using a vernier callipers **as explained in Experiment 1.** Measure the length, breadth and thickness of the block about 4 to 8 times in various positions of the block.

Tabulate your result as shown below :

Observations :

Value of the smallest main scale division = ... mm
Size of a vernier scale division = ... mm
Least count of the vernier / Or / Vernier constant (V.C.) of the vernier = ... mm
Zero error of the vernier = (1) ..... mm
(2) ..... mm
(3) ..... mm
Mean zero error = ... mm
Mean zero correction = ± ..... mm

Length of the block :

S. No.	Main scale reading in mm (a)	No. of vernier division coincident (n)	Length of the block in mm		Mean corrected length of the block (l) in mm
			Observed = (a) + n × V.C.	Corrected = Observed ± Mean Zero correction	
1.					
2.					
3.					
⋮					
8.					

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Breadth of the block :

S. No.	Main scale reading in mm (a)	No. of vernier division coincident (n)	Breadth of the block in mm		Mean corrected breadth of the block (b) in mm
			Observed = $(a) + n \times$ V.C.	Corrected = Observed ± Mean Zero correction	
1.					
2.					
3.					
⋮					
8.					

Thickness of the block :

S. No.	Main scale reading in mm (a)	No. of vernier division coincident (n)	Thickness of the block in mm		Mean corrected thickness of the block (t) in mm
			Observed = $(a) + n \times$ V.C.	Corrected = Observed ± Mean Zero correction	
1.					
2.					
3.					
⋮					
8.					

Calculations :

Volume of the given metallic block

= Mean corrected length × Mean corrected breadth × Mean corrected thickness

= $l \times b \times t$ = ... mm^3 = ... cm^3

Verification by graduated cylinder :

Volume of water in graduated cylinder before immersing the block in water in the cylinder = A = ... cm^3

Volume of water in the graduated cylinder after immersing the block in water in the cylinder = B = ... cm^3

∴ Volume of the given metallic block = B – A ..... cm^3

Precautions and Sources of Error :

Same as in Expt. 1.

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ORAL QUESTIONS

Same as in Expt. 1.

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EXPERIMENT 3

(a) To find the least count of a screw gauge.

(b) To measure the diameter of a given wire by using screw gauge and compare it by wrapping the same wire around a pencil and explain the difference.

(c) To find the volume of the given wire by using screw gauge.

(d) To find the gauge of the wire using standard table.

(e) To find the thickness of a given glass strip using screw gauge.

Apparatus :

A srew gauge ; a wire and a glass strip.

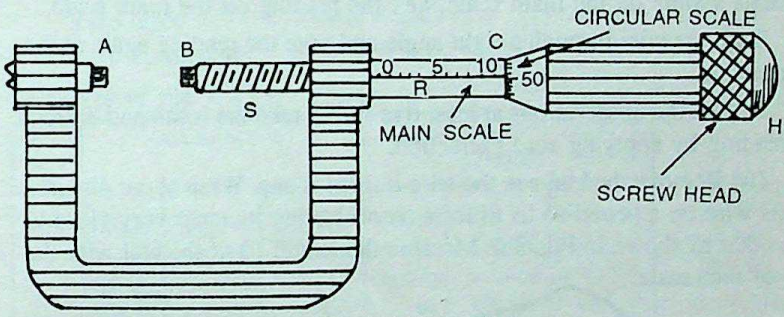

Fig. 3.1. Screw Gauge

Procedure :

(*i*) *Determine the least count* of the instrument. In order to do that bring the zero mark of the circular scale into coincidence with the reference line. Note the reading on the main scale. Give some complete rotations say four or five to the circular scale and note the reading on the main scale again. Difference of the two readings gives the distance moved by the screw. Calculate the pitch by the relation.

$$\text{pitch} = \frac{\text{distance moved by the screw}}{\text{number of rotations}}$$

Note the total number of divisions on the circular scale, then

$$\text{least count} = \frac{\text{pitch}}{\text{total number of divisions on the circular scale}}$$

(*ii*) *Find the zero correction, i.e.,* screw up untill the gap between A and B is just closed and the ratchet arrangement gives a click. If the zero

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division of the circular scale coincides with the reference line, write the zero error as nil ; otherwise reference line may be 'x' divisions towards positive side of zero of the circular scale, then

$$\text{zero error} = + x \times \text{L.C.}$$

and $$\text{zero correction} = - x \times \text{L.C.}$$

And if the reference line may be 'x' divisions towards negative side of zero of the circular scale then

$$\text{zero error} = - x \times \text{L.C.}$$

and $$\text{zero correction} = + x \times \text{L.C.}$$

(*iii*) *Diameter of the Wire*. In order to find the diameter of a given wire, place it in the gap between A and B. Turn the screw head until the ratchet arrangement gives a click. Note down the reading on the main scale. Read the division of the circular scale coinciding with the reference line. Multiply it by the least count and add it to the number of complete divisions visible on the main scale, *i.e.*, the reading on the main scale.

Turn the wire through a right angle and note the reading again at the same point.

Repeat the observations at least five times, take the mean and correct the reading by applying zero correction.

(*iv*) Remove the kinks in the wire if there is any. Wrap about 40 turns of this wire on a pencil so as to form a coil having its turns very close to each other as shown in Fig. 3.2. Measure the length (t) of the coil with the help of mm scale.

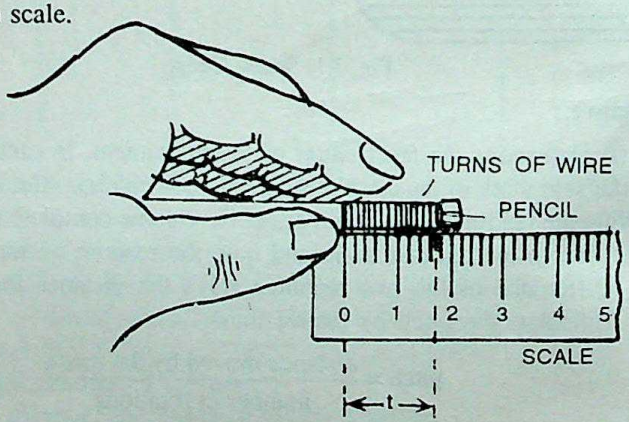

Fig. 3.2.

Count the number of turns (n) wrapped as well. Then diameter of the given wire by wrapping $= \frac{t}{n}$.

(*v*) Consult the standard table of (S.W.G.) for finding the gauge of the wire corresponding to its calculated diameter. (*See Appendix Table*).

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(*vi*) **Measurement of Thickness.** Place the glass strip in the gap between A and B. Turn the screw head until the ratchet arrangement gives a click. Note down the reading on the main scale. Read the division of the circular scale coinciding with the reference line. Multiply it by the least count and add it to the main scale reading.

Repeat it three times by placing the glass strip in different positions.

Observations and Calculations :

No. of rotations given to the screw = ...

Distance moved on the main scale = ... mm

$$\text{Pitch} = \frac{\text{distance moved on the scale}}{\text{number of rotations}}$$

Total number of divisions on the circular scale = ...

$$\text{Least count (L.C.)} = \frac{\text{Pitch}}{\text{No. of divisions on the circular scale}}$$

Zero error = $\pm x \times$ L.C.

Zero correction = $\mp x \times$ L.C. = ... cm

Diameter of the Wire :

S. No.	One direction			Mutually perpendicular direction			Mean observed diameter $d=\left(\frac{d_1+d_2}{2}\right)$ in mm
	Main scale reading (a) in mm	No. of circular division coinciding (m)	Observed diameter in mm = $a+m\times$L.C. (d_1)	Main scale reading (a) in mm	No. of circular division coinciding (m)	Observed diameter in mm = $a+m\times$L.C. (d_2)	
1.							
2.							
3.							
4.							
5.							
						Mean = ... mm	

Mean corrected diameter = (d) = ... mm

= ..... cm

The gauge of the wire from a standard table = ...

Diameter of the wire by wrapping :

Number of turns = n = ...

Length of the coil = l = ... cm

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$\therefore$ Diameter of the wire = $\frac{t}{n}$ = ... cm

Volume of the wire :

Mean corrected radius = $r = \frac{d}{2}$ = ... cm

Length of the wire = l = ... cm

Volume of the wire = $V = \pi r^2 . l$ = ... cm^3

Thickness of the Glass Strip :

S. No.	Main Scale reading (*a*) in mm	No. of circular division coinciding (*m*)	Observed thickness $t = a + m \times$ L.C. (mm)
1.			
2.			
3.			

Mean observed thickness '*t*' = ... mm

Mean corrected thickness '*t*' = ... cm

Result :

(*i*) Diameter of the wire by screw gauge = ... cm
(*ii*) Diameter of the wire by wrapping method = ... cm
(*iii*) Volume of the wire = ... cm^3
(*iv*) Gauge of the wire = ... cm
(*v*) Thickness of the glass strip = ... cm

Precautions :

1. Undue pressure should not be applied to bring the two studs in contact. For this, the screw should always be turned by the ratchet cap.
2. The screw should move freely without any friction.
3. The zero error, if any, should be noted with proper sign and taken into consideration.
4. The screw should always be moved in the *same* direction to avoid back-lash error.
5. Readings should be taken at different places along the length of the wire, taking two readings at *right angles* to other at other the same place.

Sources of Error :

The turns of the coil formed of the wire may not be in close contact with each other.

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Exercises

Q. 1. *Find the thickness of a small coin.*

Q. 2. *Find the volume of a rectangular glass plate using a vernier callipers and a screw gauge.*

Hint : Volume = Length × Breadth × Thickness.

ORAL QUESTIONS

Q. 1. *What do you mean by screw gauge ?*

Ans. It is an instrument used to measure very short lengths accurately such as thickness of paper, diameter of wire, etc.

Q. 2. *Why screw gauge is called micrometer ?*

Ans. Because it can measure distance of the order of one-millionth part of a metre, *i.e.*, 10^{-6} m *i.e.*, the least count of the screw is of the order of a micrometer.

Q. 3. *Why it is called a screw gauge ?*

Ans. Because it is based on the principle of a srew and measures, *i.e.*, gauges diameter of the wire.

Q. 4. *What is the principle of a screw gauge ?*

Ans. Its principle is that linear motion is directly proportional to the rotation given to the head.

Q. 5. *What do you mean by pitch of the screw ?*

Ans. It is the linear distance moved when its head is given one complete rotation.

Q. 6. *How is the least count of the screw determined ?*

Ans. It is determined by dividing the pitch of the screw by number of divisions on the circular scale.

Q. 7. *Is pitch related with least count ?*

Ans. Yes ; $\text{L.C.} = \dfrac{\text{Pitch}}{\text{No. of divisions on the circular scale}}$

Q. 8. *What is zero-error ? How do you find its sign ?*

Ans. When the screw is in contact with plane stud and the zero of the circular scale does not coincide with the zero of the main scale, the instrument is said to have zero-error.

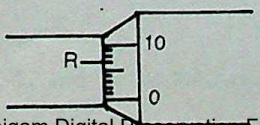

Fig. 3.3. Positive error

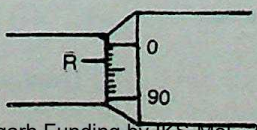

Fig. 3.4. Negative error

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When the screw is in contact with the plane stud opposite to it and if the zero of the circular scale is below the reference line, the error is said to be positive (Fig. 3.3). If the zero of the circular scale is above the reference line, the error is said to be negative (Fig. 3·4).

Q. 9. *What is zero-correction ? How is it related with zero-error ?*

Ans. Zero-correction is numerically equal to zero-error with opposite sign.

Q. 10. *What is back-lash error ? How is it avoided ?*

Ans. This error is associated with all instruments working on screw nut principle. The error is developed due to wear and tear of the screw with use. Due to looseness between the screw and the nut, the screw does not move backward or forward for a little motion of the nut (or cap) in the opposite direction. Such an error is called back-lash error.

It can be avoided by turning the screw in *one* and the *same* direction while taking all observations.

Q. 11. *What is the advantage of taking two observations mutually perpendicular to each other at each point while measuring the diameter of wire ?*

Ans. To take into account any deviation in the cross-section of the wire from its perfectly circular shape.

Q. 12. *Which is more accurate a vernier callipers or a screw gauge and why ?*

Ans. Screw gauge.

With the help of vernier callipers we can measure accurately up to 0.1 mm while with a screw gauge we can measure lengths with greater accuracy upto 1/100th of a mm.

Q. 13. *Are the values of diameter of a wire obtained by screw gauge and by wrapping method the same ?*

Ans. No ; they are different.

Q. 14. *Which method gives more accurate value and why ?*

Ans. Screw gauge method. The accuracy of measurement by an instrument depends upon the least count of the instrument. Since the least count of screw gauge is 1/100th that of a metre scale used in wrapping method, so the value of the diameter obtained by screw gauge is far more accurate.

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EXPERIMENT 4

To determine the inertial mass of a body with the help of known masses using inertial balance.

Apparatus :

A G-clamp stand, two hacksaw blades or two steel strips ; set of known masses (a weight box) ; a given body ; a platform ; a stop watch and plasticine.

Theory :

Mass is a basic property of matter and is a measure of the quantity of matter in the body. The S.I. unit of mass is the kilogram (kg.)

Newton's first law of motion leads us to the concept of inertia, a property of everybody. Newton's second law of motion proceeds a step further and provides us with a quantitative measure of inertia namely mass. Mass *as defined by Newton's second law relates the net force applied to an object to the resulting acceleration.* If $\vec{F}$ is the net force applied on a body and $\vec{a}$ is the acceleration produced in it, then, according to Newton's second law of motion, the mass of the body is given by

$$m = \frac{\vec{F}}{\vec{a}}$$

The greater the mass of an object, the greater its resistance to a change in motion—the greater its inertia and in terms of the second law of motion, we see that the greater the mass of an object for a given applied force, the smaller the change in motion—the smaller its acceleration. Mass, then is a measure of inertia and is related to the quantity of matter in a body. *We call such a mass as* **inertial mass.** All bodies are made up of atoms. The inertial mass of a body is the sum of all the atoms put together in that body. Inertial mass is given by the ratio of the resultant force applied upon a body to the acceleration produced in it along a smooth horizontal surface.

If the same external force $\vec{F}$ acting on two bodies produces in them acceleration $\vec{a}_1$ and $\vec{a}_2$ then

$$\vec{F} = m_1 \vec{a}_1 = m_2 \vec{a}_2$$

where m_1 and m_2 refer to the inertial mass of the bodies.

$$\therefore \quad \frac{m_1}{m_2} = \frac{\vec{a}_2}{\vec{a}_1} = \frac{T_1^2}{T_2^2}$$

where T_1 and T_2 are their respective vibration times.

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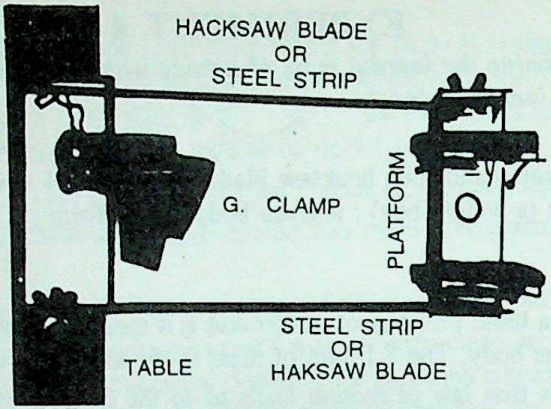

Fig. 4.1. Inertia Balance

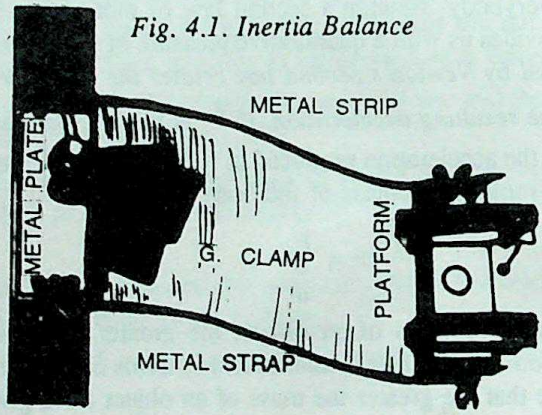

Fig. 4.2. Inertial Balance in Horizontal Motion.

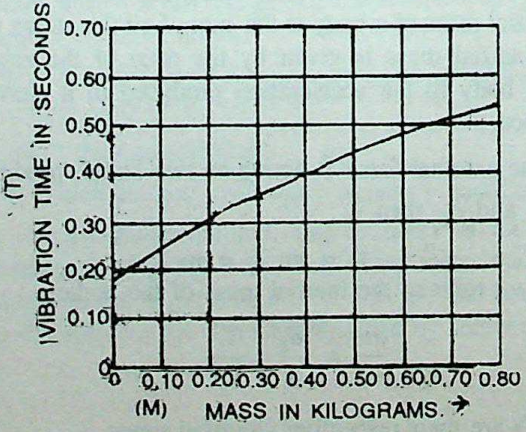

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Fig. 4.3

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If one of the bodies is taken as a standard, the above equation can be used to find the inertial mass of the other body.

The mass of a body should not be confused with weight which is the gravitational force of attraction on the body at a certain place and it differs from place-to-place. The process of measurement of mass is called weighing. Although the weight of a body differs from place-to-place, the mass of a body remains constant irrespective of place and time.

Procedure :

1. Fix the two hacksaw blades or two steel strips as shown in Fig. 4.1. *The 'hacksaw' blades (or similar metal strips) should be clamped tightly between the small metal plates using a G-clamp. It is very important to have the blades held tightly and symmetrically just where the blades emerge from the jaws as otherwise energy is lost too fast and the oscillations are badly clamped. The whole set up is clamped to the edge of the table as shown in Fig. 4.1.* At the free ends of the blades attach a small platform or a pan made of card board or wood. It is to be used for holding the body or a known mass.

2. Push the platform or the pan to one side with a finger and release it so that the platform starts oscillating in *horizontal plane* Fig. 4.2. *Since the blades vibrate horizontally, the action of the inertia balance is entirely independent of gravity,* which acts vertically. Make sure that the blade oscillates for about 10 oscillations with almost the same amplitude. This is necessary for a satisfactory experiment.

Note. The period of vibration can be increased by reducing the length of the blades protruding from the jaws.

3. Load the platform with a known mass of say 10 g. Note that the mass of the body loaded on the platform is assumed to be inertial mass. Make the platform to oscillate with a suitable amplitude *so that the mass placed on the platform does not slide when it oscillates.* For ensuring this, it is better to initially put a thin layer of plasticine on the platform. The mass placed on it will stick and will not slide.

Find out the time (t) taken for 10 oscillations by using a stop-watch and calculate the period of one oscillation, called the time period (T).

4. Repeat the activity for at least five known masses by loading the platform with each of these in turn.

5. Plot a graph between the total mass (m) of the platform and the object placed on it and its vibration time (T). Fig. 4.3. shows a graphical plot of one such set of observations. The graph in Fig. 4.3 is not a straight line. But by careful analysis of the data, the relationship can be expressed by the following equation :

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$$\frac{m_1}{m_2} = \frac{T_1^2}{T_2^2}$$

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in which m_1 and m_2 are two masses (*including* the mass of the platform or pan in each case) and T_1 and T_2 are their respective vibration times.

6. Place the body of *unknown* mass (M) on the platform. Let the platform oscillate *horizontally* as before. Measure the time period T. For this value of T, find out the total mass m' from m versus T graph as shown in Fig. 4.3.

Observations and Calculations :

Mass of the platform or the pan = M_1 = ... g

S. No.	Known mass placed on the platform or the pan M_2 in g	Total mass (m) = (M_1 + M_2) in g	Time taken (t) for 10 oscillations in sec.	Time period $(T) = \frac{t}{10}$ in sec.
1.				
2.				
3.				
4.				
5.				
6.				
7.				

For the unknown inertial mass :

Time (t') taken for 10 oscillations in sec.	Time period $T' = \frac{t'}{10}$ in sec.

From m versus T graph, the total mass (m') of the unknown object and the platform as read against

T' = Intercept of the graph on the abscissae

= ..... g

Inertial mass (M) of the body

= (m' – M_1) = ... g

Result :

Inertial mass of a given body = ... g

Precautions :

1. The position of the blades of the inertial balance should remain horizontal when the platform at its free ends, is loaded with known masses. To ensure this, *fix the blades rigidly at the clamped end. Otherwise there will be energy losses and the oscillations are badly damped.*

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2. Oscillate the blade with a suitable amplitude, so that the mass placed on the platform does not slide when it oscillates. For ensuring this, it is better to initially put a thin layer of plasticine on the platform. The mass placed on it will stick and will not slide.

3. Place each body at the centre of the platform so that it does not have a tendency to twist the blade.

4. Attach the platform at the free ends of the two hacksaw blades/ strips in such a way that centre of gravity of the body placed on it is as close to the horizontal plane bisecting the blades, as possible.

5. The number of times the inertial balance vibrates in a second of time depends upon the *length* and *stiffness* of the two supporting metal blades and upon the total mass of the pan and any objects placed on it. The more *massive* the pan and its contents, the *slower* will be the changes in their motion and the *longer* will be the time they will take to go through a complete vibration.

ORAL QUESTIONS

(Same as in Expt. 5)

Q. 1. *What is inertia ?*

Ans. By inertia we mean the inertness *i.e.*, built in reluctance of matter and hence its ability to change its position of rest or of uniform motion in a straight line without the application of an external force.

Q. 2. *How is inertia related to the mass of a body ?*

Ans. The mass of a body is a measure of its inertia. A large mass requires a large force to produce a certain acceleration because the greater the mass of the body the greater is its tendency to oppose any change in its state of rest (*inertia of rest*) or of uniform motion (*inertia of motion*).

Q. 3. *What is inertial mass ?*

Ans. Mass (m) as defined by Newton's second law of motion relates the net force ($\vec{F}$) applied to an object to the resulting acceleration ($\vec{a}$).

$$m = \frac{F}{a}$$

The greater the mass of an object, the greater its resistance to a change in motion—the greater its inertia. We call such a mass as *inertial mass*. It is given by $\frac{F}{a}$.

Q. 4. *What is gravitational mass then ?*

Ans. The mass of a body which determines the gravitational pull due to the earth acting upon it is called its gravitational mass.

Q. 5. *Is there any difference between the inertial mass and the gravitational mass of a body ?*

Ans. Experiments have failed to show any difference. Experiments show that these two masses are *equal* for a given body. □□

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EXPERIMENT 5

To find the density of a substance of the given rectangular block using a beam balance.

Apparatus :

Rectangular iron/wooden block ; vernier callipers ; physical balance and a weight box.

Diagram :

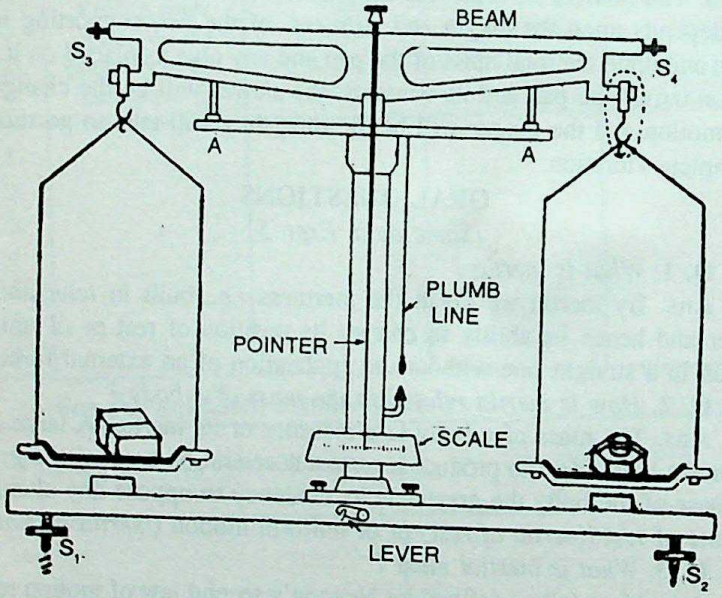

Fig. 5.1.

Theory :

If we take several solid blocks of wood or iron, we find that the larger a block is, the larger is its mass. If, however, the mass of each block is divided by its volume, the result in each case is the same which is characteristic of the substance of which the blocks are made. This result is called density.

$$\therefore \text{ Density of a substance } (\rho) = \frac{\text{Mass of the body}}{\text{Volume of the body}}$$

$$= \frac{M}{V}$$

The S.I. unit of density is kg m^{-3}.

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Procedure :

1. Measure the length, breadth and thickness of the given rectangular block by using the vernier callipers as explained in Experiment 2 and hence calculate its volume.

2. Check the setting of the physical balance carefully, *i.e.*, its pillar is vertical and when raised, its pointer swings equally on both sides of zero mark and swings without jerks.

3. Keep the rectangular block in the left-hand pan when the beam is in the arrested position. Counter poise, carefully by loading/unloading in steps the right-hand pan with known masses from the weight box. Use forceps for handling the known masses.

4. Calculate the density of the rectangular block using the formula

$$\rho = \frac{\text{mass of the rectangular block}}{\text{its volume}}$$

Observations :

Value of the smallest main scale division = ... mm

Size of a Vernier scale division = ... mm

Vernier constant (V.C.) of the vernier = ... mm

Zero error of the vernier

= (1) ..... mm (2) ..... mm (3) ..... mm

Mean zero error = ... mm

Mean zero correction = ± ..... mm

Length of the block :

S.No.	Main Scale Reading in mm (a)	No. of Vernier Scale coincident (n)	Length of the block in mm		Mean corrected length (l) of the block in mm
			Observed = $(a) + n \times$ V.C.	Corrected = Observed ± Mean Zero correction	
1.					
2.					
3.					

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Breadth of the block :

S. No.	Main Scale Reading in mm (a)	No. of Vernier Scale coincident (n)	Breadth of the block in mm		Mean corrected breadth (b) of the block in mm
			Observed = $(a) + n \times$ V.C.	Corrected = Observed ± Mean Zero correction	
1.					
2.					
3.					

Thickness of the block :

S. No.	Main Scale Reading in mm (a)	No. of Vernier Scale coincident (n)	Thickness of the block in mm		Mean corrected thickness (t) of the block in mm
			Observed = $(a) + n \times$ V.C.	Corrected = Observed ± Mean Zero correction	
1.					
2.					
3.					

Mass of the rectangular block by physical balance

= M =..... g

= ..... kg

Calculations :

Volume (V) of the rectangular block = $l \times b \times t$

= ..... mm^3

= ..... cm^3

= ..... m^3

Density of the substance of the given

rectangular block = $\rho = \frac{\text{mass of the block}}{\text{volume of the block}}$

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$$= \frac{M}{V}$$

$$= \ldots\ldots\ldots \text{ g/cm}^3$$

$$= \ldots\ldots\ldots \text{ kg m}^{-3}$$

Result :

Density of the substance of the given rectangular block

$$= \ldots\ldots\ldots \text{ kg m}^{-3}$$

Precautions and Sources of Error :

1. As regards vernier callipers, the precautions and sources of error to be observed are the same as given in Experiment 1.

2. Make sure that the scale pans of the physical balance are clean, dry and dust free as the mass of the dust may be more than its sensitivity.

3. Adjust the screws at the base of the physical balance until the plumb line hangs vertically over the fixed pointed tip.

4. Use a forcep to handle the weights. Never leave weights lying about.

5. While weighing always lower the case of the balance box to prevent disturbance due to air draughts.

6. Every balance has certain capacity *i.e.,* maximum mass which can be placed on the pans and measured with precision. Do not over load it. Find its capacity for measuring mass from its manufacturer's specifications.

ORAL QUESTIONS

(Also read Questions of Expt. 1)

Q. 1. *Define mass of a body. What is its unit ?*

Ans. The mass of a body is defined as the quantity of matter contained in it. According to Newton's First Law of Motion, the mass of a body may also be defined as the quantity of inertia possessed by the body which makes it to resist any change in its state of rest or motion.

The unit of mass is *kilogram* in SI system.

Q. 2. *Define density of a body.*

Ans. The density of a substance is defined as the mass per unit volume of that substance. This can be written as

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

Q. 3. *What is the unit of density ?*

Ans. The unit of density in SI system is *kilogram per cubic metre* or kg m^{-3}.

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Q. 4. *Define relative density of a substance ?*

Ans. Relative density of a substance is defined as the ratio of density of the substance to the density of water.

Q. 5. *What is the unit of Relative density ?*

Ans. The relative density is a number and hence it has no unit.

Q. 6. *What happens to the weight of a body when immersed in water ?*

Ans. When a body is immersed in water, an upward thrust acts upon it. Due to this upward thrust, there is a loss in the weight of the body. This loss in weight of the body is equal to the weight of the water displaced.

Q. 7. *How does density vary with temperature ?*

Ans. It decreases with the increase of temperature.

Q. 8. *What is the density in SI units of (i) Water, (ii) Mercury, and (iii) Ice ?*

Ans. (*i*) 1000 kg/m^3 at 4°C. (*ii*) 13600 kg/m^3, (*iii*) 930 kgm^{-3}

Q. 9. *Is relative density different from specific gravity ?*

Ans. No, They are the same terms.

Q. 10. *Is the relative density of a body different in different systems ?*

Ans. No, It is the same in all systems.

Q. 11. *What is the apparent weight of a block of wood floating on water ?*

Ans. Zero.

Q. 12. *Will the buoyancy be the same for a wooden block and an iron block of the same size pushed under the surface of water ?*

Ans. Yes ; the same.

Q. 13. *Why can't we extinguish burning kerosene oil by pouring water on it ?*

Ans. Kerosene oil is lighter than water. When water is poured over it, it sinks and, therefore, cannot prevent the air (responsible for burning) from coming in contact with the oil.

Q. 14. *A person carries a bucket of water weighing 20 kg in his right-hand and a fish weighing 20 kg in the other. He puts the fish in the bucket. How much does his right-hand now carry if the relative density of the fish is 1 ?*

Ans. His right-hand would carry the same weight 20 kg as before. The addition of the fish will not add anything to the weight because the weight in water will be zero, its specific gravity being one.

Q. 15. *A piece of ice is floating on water in a beaker. When it melts completely, will the level of water go up, go down or remain the same ?*

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Ans. It will remain the same.

Q. 16. *What is a Physical Balance ? What is its principle ?*

Ans. It is a lever of first order having the effort arm and the weight are equal. It is based on the principle of moments.

Q. 17. *Why are knife edges made of agate ?*

Ans. Agate is a very hard substance and does not wear out easily, hence it is used.

Q. 18. *What is the function of Plumb Line ?*

Ans. To make the beam rotate in a vertical plane.

Q. 19. *Why are there only three levelling screws in the balance ?*

Ans. Because any three points can determine a plane, so the balance can be set with its beam horizontal.

Q. 20. *What are the requisites of a good balance ?*

Ans. A good balance should be true, sensitive and stable.

Q. 21. *What is the difference between mass and weight ?*

Ans. Mass of a body is the quantity of matter contained in a body and weight is the pull exerted by the Earth on the body.

Q. 22. *What does the Physical balance measure, weight or mass and why ? Name the instrument for measuring weight.*

Ans. We measure mass of a body with a Physical Balance as the acceleration due to gravity on both the pans, being equal, will cancel out and the readings will be independent of '*g*'.

Weight is obtained by spring balance.

Q. 23. *What do you understand by the sensitiveness of a balance and how is it increased ?*

Ans. A balance is said to be sensitive when its beam is turned through an appreciable angle for a small difference of weights in the two pans. The conditions of sensitiveness are :

(*i*) the arms of the pans must be large.

(*ii*) the beam must be light.

(*iii*) the distance between the C.G. of the beam and its fulcrum, *i.e.*, the central knife edge must be small.

Q. 24. *How stability is opposed to sensitiveness ?*

Ans. A balance is said to be stable if after a small displacement it comes back to its original position as quickly as possible.

The necessary conditions for stability are :

(*i*) the arms of the beam must be small.

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(*ii*) the beam must be heavy.

(*iii*) the distance between the C.G. of the beam and its fulcrum must be large.

Thus sensitive balance cannot be stable and *vice versa*.

Q. 25. *What is the principle of a spring balance ?*

Ans. The extension produced in the spring is directly proportional to the applied force provided the force applied is not too large to stretch the spring beyond elastic limits (Hooke's law).

When the spiral spring is subjected to a tension along the axis of a spiral in a spring balance, the movement of the index along the scale (indicating the elongation of the spring) being accurately proportional to the applied force.

Q. 26. *Can a spring balance measure mass ?*

Ans. Though primarily used to measure the weight of a body, it can also measure mass accurately *but only at the place of graduation.*

Q. 27. *Define sensitiveness of a spring balance.*

Ans. It is the change in length of the spring of a balance for a *unit change* in the weight hung.

Q. 28. *How can you increase the sensitiveness of a spring balance ?*

Ans. By making the spring of the balance long (as the change in length will be large when the original length of the spring is large).

Q. 29. *Will a spring balance calibrated in India measure the weight of a body accurately in France ?*

Ans. Yes ; It will measure weight accurately.

Q. 30. *What is Archimede's principle ? To what use it has been put ?*

Ans. Archimede's Principle : When a body is wholly or partially immersed in a fluid at rest, it experiences an upward thrust which is equal to the weight of the fluid displayed by it.

It is used to determine the relative densities of solids and fluids.

□□

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EXPERIMENT 6

(a) To locate the position of no friction for the junction of three threads when it is in equilibrium under the action of three forces in the parallelogram law of vectors apparatus.

(b) To find the weight of the given body using the parallelogram law of vectors.

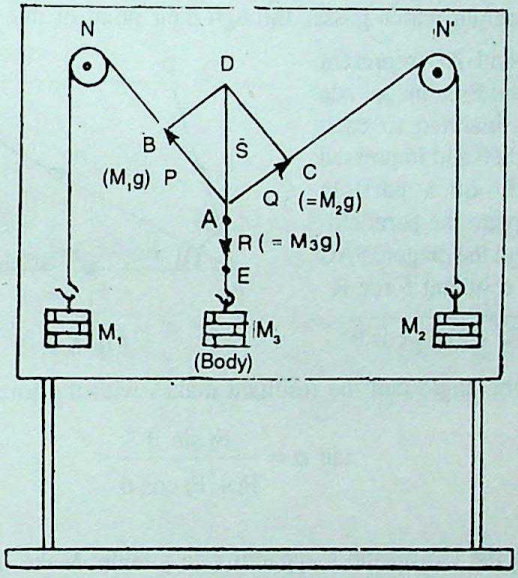

Fig. 6.1

Apparatus :

Gravesands's apparatus, hangers ; slotted weights ; thread, half metre rod, plane mirror strip ; a spring balance, set squares and protractor ; a wooden block with a hook (unknown weight).

Theory :

If a number of forces act on a body simultaneously, it is possible to find a single force, which would replace them, *i.e.,* which would produce the same effect as is produced by all the given forces. This force is called the **resultant force.** If we apply to the body a force equal and opposite to the resultant, the body would be in equilibrium ; for the resultant and this applied force would balance each other. This applied force is, therefore, called the **equilibrant force.**

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Since force is a vector quantity the resultant of two or more forces cannot be determined by applying the arithmetical laws, but by the method of compounding vectors. Thus, when we have only two forces acting on a body at a certain angle, we might compound them by the law of parallelogram of forces which may be stated as follows :

Law of Parallelogram of Forces

If two forces, acting simultaneously on a particle be represented in direction and magnitude by the two adjacent sides of a parallelogram, their resultant is represented in direction as well as magnitude by the diagonal of the parallelogram which passes through their point of intersection.

Let AB and AD represent two forces F_1 and F_2 in magnitude and direction, inclined to each other at an angle θ and impressed simultaneously on a particle Fig. 6.2. Complete the parallelogram ABCD and the diagonal AC represents the resultant force R.

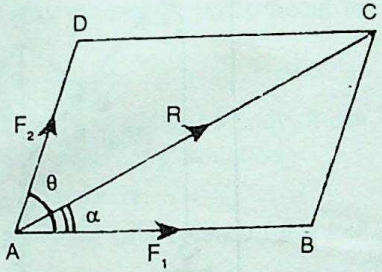

Fig. 6.2.

$$R = \sqrt{F_1^2 + F_2^2 + 2F_1F_2 \cos\theta}$$

If α be the angle that the resultant makes with the force F_1 then

$$\tan\alpha = \frac{F_2 \sin\theta}{F_1 + F_2 \cos\theta}$$

Procedure :

1. Place the Gravesand's apparatus on a table. Make it vertical by a plumb line. See that the pulleys are frictionless so as to rotate free about their axis. **If not, oil them.**

2. Fix a sheet of paper on the board by means of drawing pins.

3. Pass a thread over the two polleys with hangers at its ends and then knot another thread in its middle and attach the given wooden block (unknown weight) to its lower end. Add slotted weights to the hangers till the knot A (Fig. 6.1.) lies approximately at the centre of the sheet and none of the hangers and the given body touches the vertical board. When the weights are steady it would mean that the point A is in equilibrium under the action of three forces represented by the weights. In the case of perfect equilibrium, a slight disturbance of the point A should bring it back to the original position but generally the position of A may vary over a small area on account of friction at the pulleys, etc.

4. To mark the direction of the forces, place a plane mirror strip lengthwise under each thread in turn and mark two points one on either

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end by placing your eye in such a position that the image of the thread in strip is covered by the thread itself.

5. Remove the hangers along with weights one-by-one and weigh them with a spring balance carefully and note the weights. Find the zero error of the spring balance before weighing.

6. Unclamp the board and place it on the table. Join the points marked under each string and produce them to meet at their common junction A which is the position of no friction for the junction of three threads.

7. Choose a suitable scale to indicate the forces so that you may get a fairly large parallelogram. From the common point A mark off lengths AB and AC representing the respective forces P and Q. On adjacent sides AB and AC complete the parallelogram ABCD and draw the diagonal AD which represents the resultant S of P and Q and mark arrow heads to indicate the direction of forces. Also produce EA (Fig. 6.1) and if the experiment is correctly performed, EA produced should pass through D.

8. Measure AD and calculate the force which it represents. It should be equal to its equilibrant in magnitude, *i.e.*, the unknown weight (R) of the given body.

9. Repeat the experiment twice more by changing weights in the hangers and find the mean value of the unknown weight R.

10. Verify the result by weighing the body with a spring balance.

Observations and Calculations :

Zero error of spring balance = ... g

Scale : 1 cm = n (say) g

No. of obs.	Force		Diagonal AD (cm)	Resultant Force represented by the diagonal AD (S) in g =AD × *n*	Unknown weight of the given body R=S=AD× *n* (g)
	P	Q			
1.					
2.					
3.					

Mean value of unknown weight = ... g

(*a*) The common junction A is the position of no friction.

(*b*) The unknown weight of the given body by experiment

= ..... g = ... N

The unknown weight of the given body by spring balance

= ..... g = ... N

% error = ...

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Precautions :

(*i*) The pulleys should be frictionless so as to rotate freely about their axes.

(*ii*) The apparatus should be vertical.

(*iii*) The weights should hang *freely* and not touch the board.

(*iv*) The direction of the forces should be marked with the help of a mirror strip placed *lengthwise* using a sharp pencil.

(*v*) The weights should be as large as possible to be so adjusted that the meeting point of the forces is near the middle of the paper.

(*vi*) Weights along with their hungers should be weighed with a spring balance, taking into account its *zero error* if any.

(*vii*) The scale should be so selected, as to get a fairly large parallelogram.

Sources of Error :

1. Weights may not be accurate.
2. Pulleys are not perfectly smooth.
3. Lines drawn may not be very sharp and fine and slight inaccuracy in making the directions.

ORAL QUESTIONS

Q. 1. *Define : Force.*

Ans. It is that agency which produces or tends to produce ; destroys or tends to destroy the state of rest or of uniform motion in a body.

Q. 2. *What is its unit in the SI system and define it ?*

Ans. *Newton.*

One newton is that much force which produces in a mass of 1 kg an acceleration of 1 ms^{-2}.

Q. 3. *How kilogram weight is related to newton ?*

Ans. 1 kg weight = 9.81 newtons

Q. 4. *Define weight of a body. What is its unit ?*

Ans. Weight is the pull exerted by the earth on the body and is equal to mass × acceleration due to gravity. It is obtained by a spring balance.

It has the same units as force, *i.e.* newton and kg wt.

Q. 5. *What do you mean by resultant force and component forces ?*

Ans. *Resultant force* is that single force which produces the same effect on a body as is produced by a large number of independent forces. The various forces are called its *components*.

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Q. 6. *What are scalar quantities ? How are they added up ?*

Ans. Those quantities which have *magnitude only* and no direction are called scalar quantities, *e.g.*, mass, length, time, speed, work, power, energy, etc.

They are added up *algebraically.*

Q. 7. *What are vector quantities ? How are they added up ?*

Ans. Vector quantities are those quantities which have magnitude as well as direction, *e.g.*, Force, Velocity, Displacement, Momentum, etc.

They are added up according to the Laws of composition of vectors, *i.e.*, by Parallelogram Law of vectors or Triangle Law of vectors or Polygon Law of vectors.

Q. 8. *What do you mean by composition of vectors ?*

Ans. It is a process of compounding two or more than two vectors into a single vector, *i.e.*, resultant vector.

Q. 9. *State Parallelogram Law of forces.*

Ans. *Parallelogram Law of forces :*

If two forces act on a particle simultaneouly and they can be represented by the two adjacent sides of a parallelogram, their resultant is represented in magnitude and direction by the diagonal of the parallelogram passing through the point where the two sides meet.

Q. 10. *State Triangle Law of forces.*

Ans. *Triangle Law of forces :*

If two forces act on a particle simultaneously and they can be represented in magnitude and direction by the two sides of a triangle *taken in order*, their resultant is represented in magnitude and direction by the third side of the triangle taken in the *opposite order.*

Q. 11. *State Polygon Law of forces.*

Ans. *Polygon Law of forces :*

If a number of forces act on a particle simultaneously and they can be represented in magnitude and direction by the sides of a polygon taken in order, their resultant is completely represented in magnitude and direction by the closing side of the polygon taken in the opposite order.

Q. 12. *What is resolution of forces ?*

Ans. It is a process of resolving a resultant force into its component forces.

Q. 13. *What are rectangular components of a force ?*

Ans. If the components of a force are at right angles to each other, then they are called rectangular components.

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Q. 14. *Distinguish between rest and equilibrium.*

Ans. *Rest* means motion and *equilibrium* means no acceleration. If a body does not change its position with respect to its surroundings then it is said to be at rest and if a number of forces acting on a body simultaneously do not change its state of rest or of uniform motion then the body is said to be in a state of equilibrium.

Q. 15. *How did you find the unknown weight of a given body ?*

Ans. By applying Parallelogram Law of forces.

Q. 16. *Is it a good method ?*

Ans. No ; owing to the *friction* at the pulleys, it does not give accurate result.

[For further questions on friction read questions in Expt. 9]

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EXPERIMENT 7

To find the downward force along the inclined plane acting on a trolley/roller on account of gravitational pull of earth and study its relationship with the angle of inclination of the inclined plane.

Apparatus :

Inclined plane with glass top with a pulley, pan, weight box, strong thread, roller or trolley, half metre scale, spirit level, spring balance.

Theory :

An inclined plane or a plane board hinged at its lower end, and supplied with some means of adjusting its inclination at several different values. At the upper edge of the inclined plane is usually fixed a pulley, over which a cord passes. To the end of the cord on the plane the load W is attached, while from the hanging end of the cord, weights from the weight box can be suspended to exert the force P on the cord (Fig. 7.2). In order to eliminate friction between the load W and the plane, W is usually a small roller, supported on an axle carried by a suitable framework, to which framework the cord is attached. In some forms of the apparatus the pulley and hanging weight are replaced by a spring balance which automatically adjusts itself to exert the required force P at any inclination, and P can be read off directly.

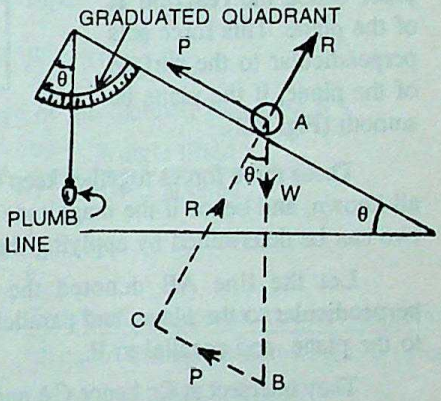

Fig. 7.1.

The angle θ can be measured by means of a protractor placed with its edge along the horizontal base and its centre at the centre of the hinge but it is better to have a graduated Quadrant fitted near the top of the plane (Fig. 7.1), with a plumb line hinging from its centre. If the zero-line of the Quadrant stands out at right angles to the plane, the angle θ is read off as the angle between the plumb line and this zero line. This method is preferable to the first, as it is necessary to level the base by means of a spirit level if the first method is used, and other errors easily creep in when measuring the angle θ.

If a load W is resting on an inclined plane, it may be maintained in equilibrium on the plane, or pulled without acceleration up the plane, by

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a force P acting parallel to the surface of the plane. The force P is much smaller than the weight of the body W, the value of P diminishing as the inclination of the plane diminishes.

Consider the forces acting on a body of weight W, which is just maintained in equilibrium on a plane inclined to the horizontal, at an angle θ, by a force P acting along the plane. We have first its weight W acting vertically downwards, secondly the force P acting along the plane, and in addition to these there is a force exerted by the plane called the **reaction R** of the plane. This force acts perpendicular to the surface of the plane, if the plane be smooth (Fig. 7.2).

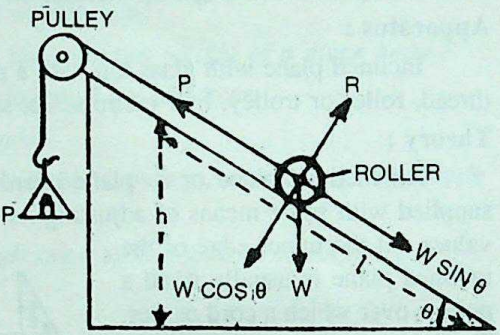

Fig. 7.2

These three forces together keep the body at rest ; their directions are all known, and hence if the magnitude of one of them is known, the other two can be determined by applying the principle of the triangle of forces.

Let the line AB denoted the weght W (Fig. 7.1). Draw AC perpendicular to the plane, and parallel to the reaction R, and BC parallel to the plane, and parallel to P.

They intersect at C ; hence CA and BC represent R and P respectively.

The angle CAB is equal to the angle θ ; since AC is perpendicular to the plane and AB is perpendicular to the base. Thus

$$\frac{BC}{AB} = \sin \theta$$

But BC and AB represent P and W,

therefore, $$\frac{P}{W} = \sin \theta$$

$$\boxed{P = W \sin \theta}$$

A somewhat simpler proof is obtained if we consider the **energy gained** by the weight when pulled up the plane, and **work done** by P in pulling it up the plane.

The work done by a force is measured by the product of the magnitude of the force and the **effective displacement**, or the distance moved by the point of application in the direction of the force. Suppose the force P

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pulls the body through a distance l, measured along the inclined plane, and in so doing raises it through a vertical distance h, which we may call the height of the plane.

The height of the top of the plane above the bottom is h, hence the weight gains an amount of potential energy = Wh, when raised to the top.

The force P acts through a distance l in its own direction when pulling the weight up the plane, if l is the length of the plane, hence the work done by the force is Pl.

By the principle of conservation of energy,

Energy gained = work done

or Output = Input

so that $Wh = Pl$ or $\frac{W}{P} = \frac{l}{h}$

Now Mechanical advantage of the Inclined Plane (M.A.)

$$= \frac{W}{P} = \frac{\text{Weight lifted}}{\text{Power applied}}$$

and velocity ratio (V.R.)= $\frac{l}{h}$

$$= \frac{\text{distance through which power is applied}}{\text{distance through which weight is lifted}}$$

$\therefore$ Efficiency of the Inclined plane $= \frac{\text{M.A.}}{\text{V.R.}} \times 100\%$

Also, $\text{Efficiency} = \frac{\text{Output}}{\text{Input}} \times 100\%$

Since $Wh = Pl$

$\therefore$ $\text{Weight (W)} = P \cdot \frac{l}{h} = \frac{P}{\sin\theta}$.

Thus knowing P and sin θ, the unknown weight (W) can be calculated.

Procedure :

1. First of all see that the pulley of the inclined plane and the roller rotate freely about their axis and if not, oil them.

2. Check up that the board with glass top is horizontal when it coincides with base board *i.e.*, when θ = 0. If not, adjust it horizontal.

3. Suspend the spring balance in a clamp stand. Find the magnitude of each scale division and also find the zero error of the spring balance. Find the weight of the scale pan and that of the roller.

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4. Pass a string over the pulley. Attach the roller lying on the plane to its one end and pan to the other end. Make sure that the thread does not touch any part of the horizontal board or the table.

5. Go on adding weights into the pan till the roller just begins to move upward on tapping the plane. Note the weights placed in the pan (p_1). Go on decreasing the weights placed in the pan now till the roller just begins to move downward on tapping the plane. Note again the weights placed in the pan (p_2). Take the mean of p_1 and p_2 , *i.e.*, $\left(\frac{p_1 + p_2}{2}\right)$ and add it to the weight of the scale pan to get the force applied (P) or the effort applied.

6. Apply different forces P over the pulley, using different inclinations of the plane. Note corresponding values of P and θ, taking five or six different inclinations.

7. Plot a graph between sin θ and P and also between P and θ and compare the two graphs.

Observations and Calculations :

Zero error in the spring balance = ... g

Corrected weight of the scale pan = p = ... g

Corrected weight of the roller = W = ... g

S. No.	Weights placed in the pan when roller is moving		Component of gravitational force (P) $= p + \left(\frac{p_1 + p_2}{2}\right)$ in g	Inclination θ	sin θ
	up (p_1) in g	down (p_2) in g			
1.					
2.					
3.					
4.					
5.					
6.					

If the Quadrant for measuring θ is not fitted to the apparatus, measure h and l directly, taking *the same point on the plane each time* and measuring its height above the base and its distance *along the plane* from the centre

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of the hinge. The table of observations would then be arranged as follows :

S. No.	Weights placed in the scale pan when roller is moving		Component of gravitational force $(P) = p + \left(\frac{p_1 + p_2}{2}\right)$ in g	h in cm	l in cm	$\sin\theta = \frac{h}{l}$	θ
	up (p_1) in g	down (p_2) in g					
1.							
2.							
3.							
4.							
5.							
6.							

Result :

(*i*) The downward force along the inclined plane acting on the roller/trolley on account of the gravitational pull of the earth

$= P =$ ..... g

$=$ ..... N

(*ii*) The graph between P and $\sin\theta$ is a .....

The graph between P and θ is .....

Precautions :

(*i*) The pulley and the roller/trolley should be free from friction.

(*ii*) The thread between the roller and the pulley should be parallel to the plane.

(*iii*) The surface of the roller/trolley and that of the inclined plane should be clean, dry, plane and smooth.

Sources of Error :

1. The weights in the weight box may not be standard.

2. The pulley and the roller/trolley may not be frictionless.

3. The surface of the inclined plane may not be equally plane everwhere.

ORAL QUESTIONS

(Same as in Expt. 8 and Expt. 11).

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EXPERIMENT 8

To find acceleration of a body and to study how the acceleration of a body depends on the force acting on it and the mass of the body.

Apparatus :

Ticker tape timer, loose roll of tape, carbon disc, 4 trolleys, raised runway or a horizontal laboratory table, metre-rule, elastic cords with eyelets, a.c. supply.

Theory :

Newton's Second Law of Motion can be stated as "the rate of change of momentum of an object is equal to the unbalanced force applied to it causing the change in momentum to take place in the direction of the force".

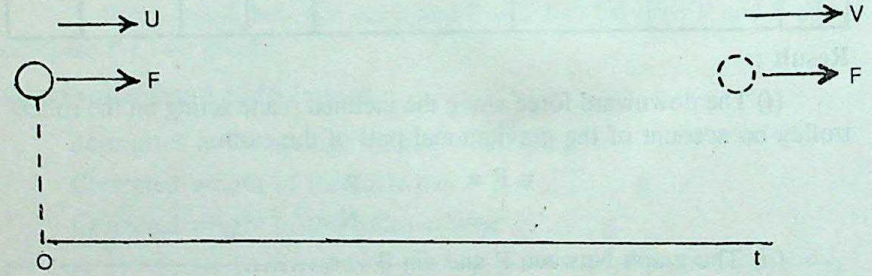

Fig. 8.1. A mass being uniformly accelerated.

Consider a mass m moving with an initial velocity u. It is accelerated to a velocity v in a time t by the application of a constant unbalanced force F throughout the t seconds (Fig. 8.1)

Change in momentum $\Delta p = + mv - (+ mu)$

$$\Delta p = mv - mu$$

Rate of change of momentum

$$\frac{\Delta p}{t} = \frac{mv - mu}{t}$$

Unbalanced force $$F = \frac{m(v - u)}{t}$$

$$\boxed{F = ma}$$

where a = acceleration which by definition is the rate of change of velocity.

The Force F has units of kg ms^{-2} which are known as newton (N).

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From Newton's Second Law expressed in the form F = *ma* it can be seen that, for a fixed mass, *m*, the acceleration *a* is directly proportional to the applied unbalance force F.

$$a \propto F$$

The equation F = *ma* also states that for a given unbalanced force F, the acceleration *a* is inversely proportional to the mass *m i.e.*,

$$a \propto \frac{1}{m} \quad \text{or} \quad a = \frac{F}{m}$$

Procedure :

[A] To test the relationship a ∝ F :

1. Set up the apparatus shown in Fig. 8.2 but without the elastic cord attached.

The first requirement is to compensate for the frictional force between the trolley and the runway or the horizontal laboratory table. This is done by raising one end of the runway or horizontal laboratory table until a trolley, with a tape attached, shows uniform velocity (*i.e.*, the dots on the ticker tape are equally spaced) when it is given a gentle push down the inclined runway or horizontal laboratory table.

Diagram :

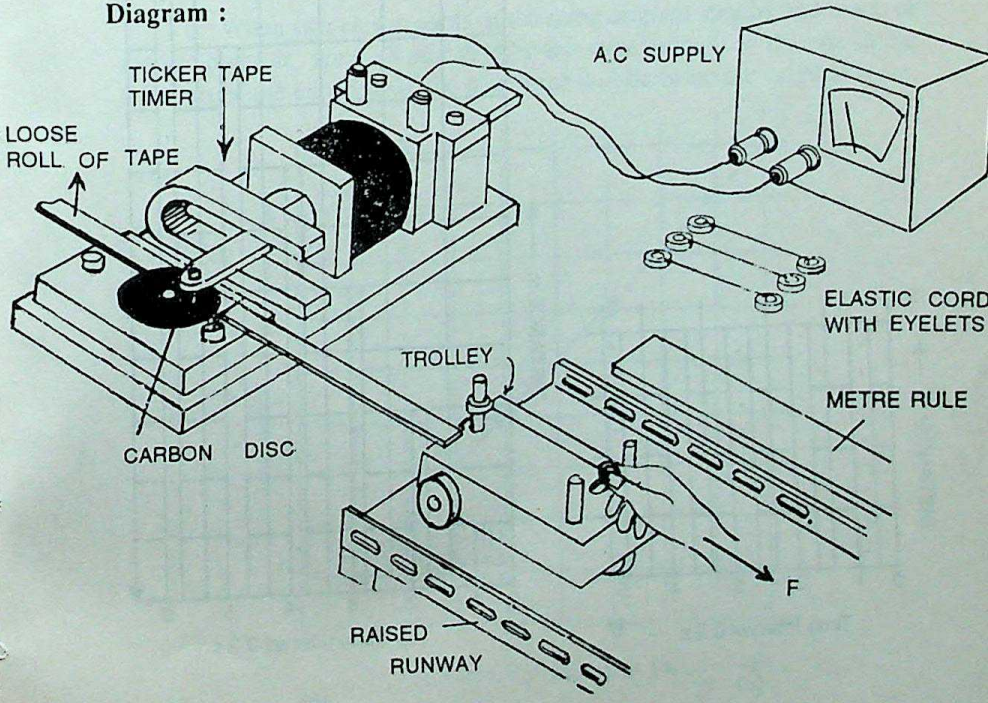

Fig. 8.2

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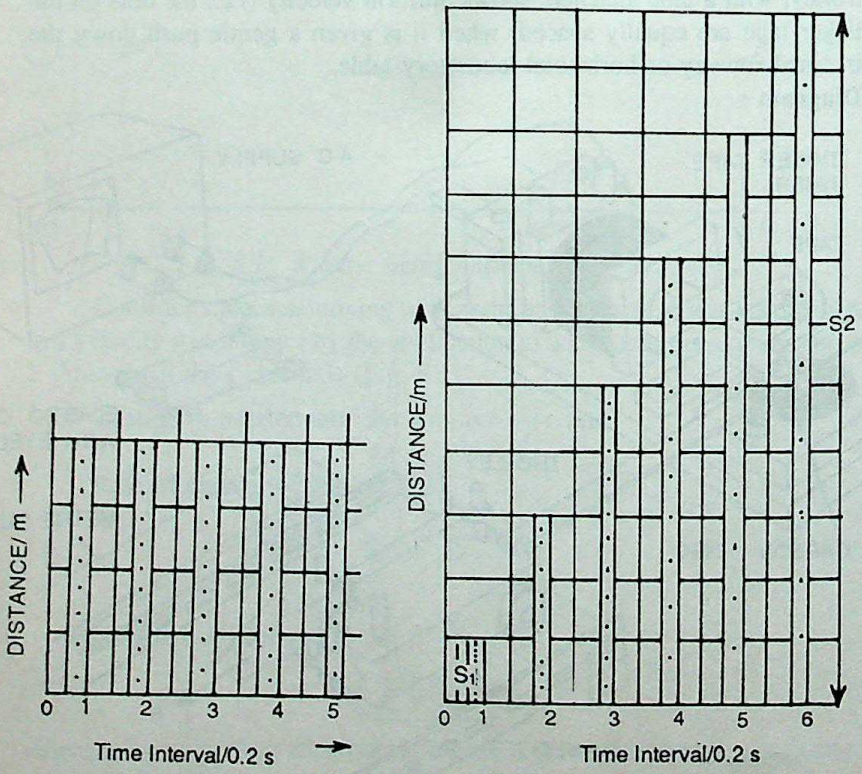
2. Now attach one elastic cord to the single pillar on the trolley and stretch it until it is level with the double pillars. A force F is required to stretch the cord, and this force F will remain constant provided the length of the stretched cord is kept constant while you pull the trolley down the runway or horizontal laboratory table. Thread part of a 3 *m* length of ticker tape under the carbon disc and then stick it on one end of the trolley.

Start the timer and stretch the cord while still holding the trolley. After you release the trolley you must move alongside the runway holding the stretched cord so that its length remains constant. **You may have to practise this because the cord will try to shorten when the trolley is first released and you must apply just the right force to prevent this happening.**

3. After a successful run, detach the tape and, disregarding the first series of dots, cut is up into strips which each represent 10 vibrations or 0·2 s (10 × 0·02 s). These strips can be stuck on a sheet of graph paper to give a chart like that in Fig. 8.3 (*b*).



(*a*) (*b*)

Fig. 8.3. Tape charts for (a) uniform motion on the friction compensated runway and (b) accelerated motion.

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4. Fig. 8.3. (*a*) shows the chart obtained when the trolley runs down the runway at uniform velocity *i.e.*, covering equal distances in equal time intervals on a *friction-compensated runway.*

5. Using the chart in Fig. 8.3 (*b*) the average acceleration *a* can be calculated from

$$a = \frac{(v - u)}{t}.$$

The average final velocity *v* for the sixth length of tape is calculated from

$$v = \frac{S_2}{0{\cdot}2}$$

Likewise, the original velocity is calculated as

$$u = \frac{S_1}{0{\cdot}2}$$

from the first length of the tape.

The time interval *t* between the first and sixth tapes is $5 \times 0{\cdot}2 = 1{\cdot}0$ s.

Hence

$$a = \frac{\frac{S_2}{0{\cdot}2} - \frac{S_1}{0{\cdot}2}}{1} = \frac{S_2 - S_1}{0{\cdot}2} \text{ ms}^{-2}$$

6. When two elastic cords of the same original lengths and made of the same elastic are both stretched by the same amount as the one in the first part of the experiment, the new force will be twice the original force.

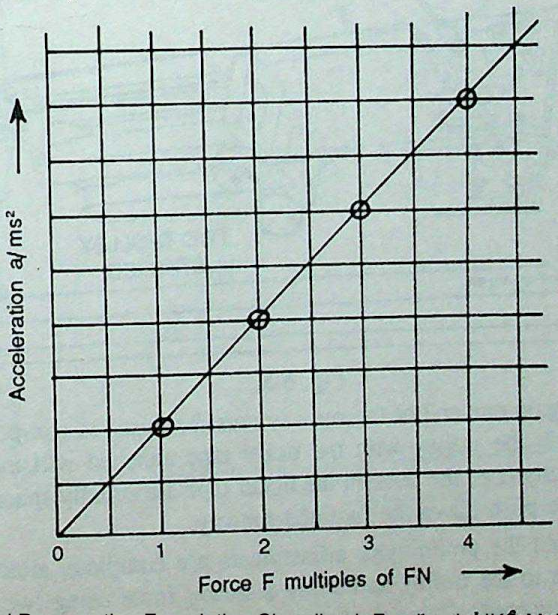

Fig. 8.4. A graph of acceleration against the force applied to the trolley

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Repeat the experiment using two, three and four stretched cords to apply forces of 2F, 3F and 4F respectively to the same trolley. In each case calculate the acceleration a as shown above.

7. Plot a graph of 'a' against 'F'. It should be a straight line passing through the origin as shown in Fig. 8·4.

[B] To test the relationship $a \propto \frac{1}{m}$:

(i) Again set up the apparatus shown in Fig. 8.2 but this time keep the accelerating force F constant by using two or three elastic cords and instead vary the mass the force acts upon. First run a single trolley, then two, three and four trolleys stacked together (Fig. 8.5). **All the trolleys should be of equal mass m,** so that the total mass is increased by the same amount each time. Alternatively, you could add metal blocks or standard masses equal in mass to the trolley, to a single trolley.

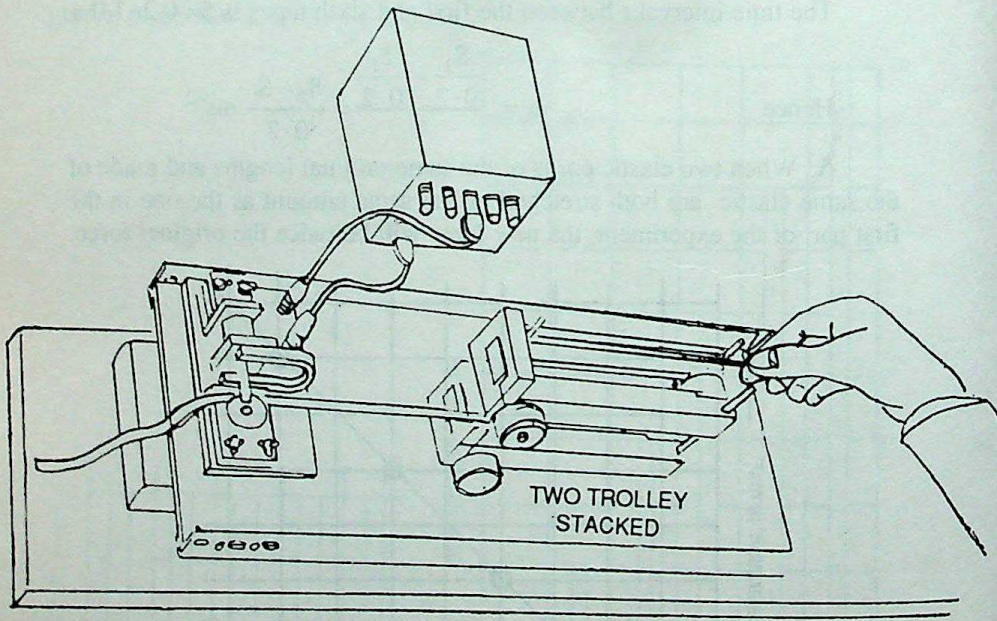

Fig. 8.5.

Once again one end of the runway must be raised to compensate for friction so that the trolley with the ticker tape attached will move with uniform velocity (*i.e.*, the dots on the ticker tape are equally spaced) when given a gentle push down the inclined runway.

(*ii*) When the preliminary adjustments are complete, attach a 3 m length of tape to the trolley and apply a steady force using two or three stretched elastic cords. Using the technique shown in Fig. 8.3 (*b*), calculate the acceleration a and hence find $1/a$ for the single trolley.

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(*iii*) Now double the mass to be accelerated by stacking a second identical trolley on the top of the first one or by adding standard masses equal in value to the mass of the trolley. Since the mass is now double, the weight is also doubled and therefore the frictional force will increase. Thus the runway must be raised a little higher so that it is friction-compensated for the double mass.

Now accelerate the double mass using the same two or three cords and determine a and $1/a$ from the tapes.

Repeat the experiment with mass trebled and quadrupled.

(*iv*) Plot a graph of mass m against reciprocal of acceleration $1/a$. It should be a straight line through the origin similar to Fig. 8.6.

Observations and Calculations :

[A] For 'a' versus 'F' graph :

S.No.	Force (F)	Acceleration $a = \frac{S_2 - S_1}{0{\cdot}2}$ ms^{-2}
1.	1 F	
2.	2 F	
3.	3 F	
4.	4 F	

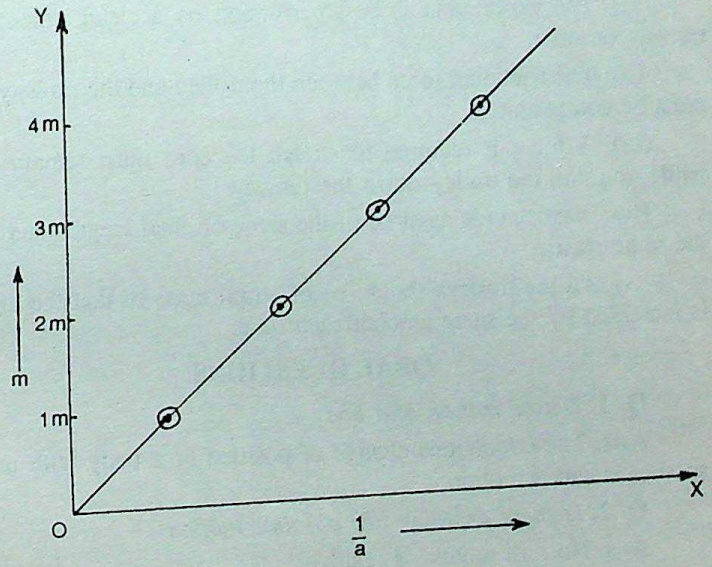

Fig. 8.6. A graph of mass of the trolley against the reciprocal of its acceleration.

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[B] For 'm' versus '1'/a graph :

S.No.	Mass (m)	Acceleration $a = \frac{S_2 - S_1}{0 \cdot 2}$ ms^{-1}	$\frac{1}{a}$
1.	1 m		
2.	2 m		
3.	3 m		
4.	4 m		

Result :

(*i*) A graph of a against F is a straight line passing through the origin. This verifies the relationship

$$a \propto F$$

(*ii*) A graph of m against $1/a$ is a straight line passing through the origin. This verifies the relationship

$$m \propto \frac{1}{a} \text{ or } a \propto \frac{1}{m}.$$

Precautions :

(*i*) The experiment is best performed on a clean, smooth, plane runway or table.

(*ii*) The frictional force between the trolley and the runway or table must be compensated.

(*iii*) A force F required to stretch the cord must remain constant while you pull the trolley down the runway.

(*iv*) Elastic cords must be of the same original lengths and made of the same elastic.

(*v*) All the trolleys should be of equal mass so that the total mass is increased by the same amount each time.

ORAL QUESTIONS

Q. 1. *Define motion of a body.*

Ans. The continuous change of position of a body with respect to another is called motion.

Q. 2. *Is there anything like absolute motion ?*

Ans. No ; all motion is relative.

Q. 3. *What is displacement of a body ?*

Ans. A change of position of a body from one point to another is called its displacement. It is described in terms of two quantities, a *distance*

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and a *direction*. The displacement of a body will change if there is any change in either its magnitude or direction or both.

Q. 4. *Define uniform motion of a body.*

Ans. An object that moves through equal distances in equal intervals of time, however small these intervals may be, is said to be in uniform motion.

Q. 5. *What is non-uniform motion ?*

Ans. When a body moves over unequal distances in equal intervals of time, it possesses non-uniform motion.

Q. 6. *Distinguish between speed and velocity.*

Ans. *Speed* is the ratio of the distance travelled by any object, irrespective of its direction, to the time it takes to travel that distance.

The *velocity* of a moving body is the rate of change of position of the body in a particular direction. In other words, the velocity of a moving body may also be defined as its speed in a particular direction.

Both are measured in ms^{-1}.

Q. 7. *What is uniform velocity ?*

Ans. If a body not only traverses equal distances in equal intervals of time, however small, these intervals may be, but also continues to move in the same direction, it is said to possess uniform velocity.

Q. 8. *Define instantaneous velocity of a body.*

Ans. The instantaneous velocity of a body is the actual value of the velocity of the body at any point of its path or at any instant of time.

Q. 9. *Define acceleration of a body.*

Ans. It is the rate of change of velocity of a body. Acceleration is the ratio of the change in velocity to the time over which this change occurs. Its SI unit is ms^{-2}.

Q. 10. *If the distance travelled by a body varies directly as the time, what conclusion do you draw about its motion and force ?*

Ans. The speed is *constant* and the force acting on it is *zero*.

Q. 11. *You observe an object covering distances in direct proportion to the square of time elapsed. What conclusion might you draw about its acceleration ? Is it increasing, decreasing, zero or constant ?*

Ans. The acceleration in this case is constant. If S is the distance covered and t, the time elapsed, then $S \propto t^2$ or $S = kt^2$ where k is a constant.

We also know that $S = \frac{1}{2} at^2$ where a is a uniform acceleration.

$$k = \frac{1}{2} a$$

i.e., a is constant.

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Q. 12. *When does a body possess uniformly acceleration motion ?*

Ans. A body is said to move with uniformly accelerated motion if its velocity increases gradually, *i.e.*, increases by equal amounts in equal intervals of time, however small these intervals may be *e.g.*, a body falling freely under the action of gravity ; a steel ball rolling down an inclined plane etc.

Q. 13. *What was Galileo's best known contribution to the science of kinematics ?*

Ans. Galileo's best known contribution to the science of kinematics was his discovery that the free fall acceleration is exactly the same for any object. Given an absence of air resistance, each object will fall to earth with exactly the same acceleration *i.e.*, 9.8 ms^{-2}.

Q. 14. *State Newton's first law of motion or law of inertia.*

Ans. According to Newton's first law of motion, every body continues to be in its state of rest or of uniform motion in a straight line unless and until it is compelled by some external force to change its state of rest or of uniform motion.

Q. 15. *State Newton's second law of motion.*

Ans. According to Newton's second law of motion, the rate of change of momentum produced in a body is directly proportional to the impressed force and takes place in the direction of the force applied.

Q. 16. *What do these laws give us ?*

Ans. Newton's first law of motion gives us the definition of force whereas Newton's second law of motion gives the measurement of force *i.e.*, F = *ma* where F is the force applied on a mass *m* and *a* is the acceleration produced in it.

Q. 17. *Define force and give its SI unit.*

Ans. Force is that agency which produces or tends to produce, destroys or tends to destroy motion in a body.

It is measured by the product of mass and acceleration. Its SI unit is *newton* (N).

Q. 18. *How is one newton related to dyne ?*

Ans. 1 newton = 10^5 dynes

Q. 19. *Define energy. Give its SI and c.g.s. units.*

Ans. It is the capacity of a body to do work. SI unit of energy is *joule* (J) and c.g.s. unit of energy is *erg*.

Q. 20. *How joule and erg are related to each other ?*

Ans. 1 joule = 10^7 ergs.

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Q. 21. *Name the two kinds of energy.*

Ans. Energy is of two kinds :

(*a*) Potential energy (P.E.)

(*b*) Kinetic energy (K.E.)

Q. 22. *Define P.E. and mention its SI unit.*

Ans. Potential energy is the energy possessed by a body due to its position or configuration. P.E. of a body = mgh where m is the mass of the body, g is acceleration due to gravity and h is the height of the body from its zero level or mean position.

Its SI unit is *joule* (J).

Q. 23. *Define K.E. of a body and mention its SI unit.*

Ans. Kinetic energy of a body is the energy possessed by it due to its motion.

K.E. = $1/2\ mv^2$ where m is the mass of a body and v is its velocity. Its S.I. unit is *joule* (J).

Q. 24. *State law of conservation of energy.*

Ans. According to law of conservation of energy

(*a*) energy can neither be created nor destroyed ;

(*b*) the total amount of energy in this universe is constant ; and

(*c*) when a certain amount of energy in one form is expended, its exact equivalent amount reappears in one or more of the other forms.

Q. 25. *What is the ultimate form of energy in all the inter-changes in the form of energy ?*

Ans. Sooner or later, it assumes the form of *heat*, which in due course becomes distributed throughout space. It probably becomes unavailable, but is still there, though scattered.

Q. 26. *Enumerate two examples of law of conservation of energy.*

Ans. (1) A body falling freely under gravity.

(2) A vibrating pendulum.

Q. 27. *What is dissipation of energy ?*

Ans. The energy which disappears as heat and cannot be used again for any useful purpose is said to have been dissipated.

Q. 28. *What is transformation of energy ?*

Ans. It is the change of energy from one form to another. For example, when a body falls freely under gravity from a certain height, its P.E. changes into K.E. when it hits the ground.

□□

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EXPERIMENT 9*

(a) To find the force of dynamic (sliding) friction for a wooden block on a horizontal plane.

(b) To find the force of rolling friction for a wooden block moving on rollers on a horizontal plane.

Apparatus :

Wooden block with a hook, a pulley which can be fixed at the edge of a table and a flat plate of glass (or an inclined plane apparatus with glass top and pulley), a light scale pan, a weight box with fractional weights, a spring balance, spirit level and thread.

Diagram :

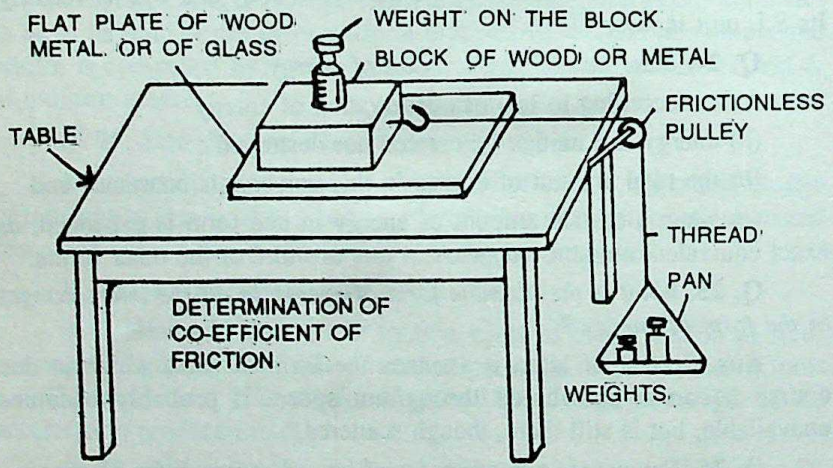

Fig. 9.1.

Theory :

The surfaces of bodies are never perfectly smooth. When two bodies are in contact and an attempt is made to slide one over the other, an opposing force called *force of friction* arises as a reaction to the applied force and acts in the opposite direction. The maximum force of friction that can be called into play between any two surfaces is known as **limiting friction** (F). This limiting friction is directly proportional to the **Normal reaction** (R) or the force acting normally on the surfaces in contact with each other.

*It is included in the list of activities. Hence it is not to be given as an experiment.

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Mathematically, $F \propto R$

or $\boxed{F = \mu R}$ where μ is coefficient of friction.

This constant depends upon the nature of the surfaces in contact and the material of the bodies.

The force required to *start* two surfaces slipping over each other when pressed together with a given force is greater than the force necessary to keep them *moving* over each other when once they are started. We thus have two frictional forces for a given force perpendicular to the faces. One of these is called the **static frictional force,** being equal to the force that has to be exerted to start the motion, or **the force exerted on each other by the two surfaces when at rest.** The other force is called the **dynamic frictional force** being equal to **the force required to keep the surfaces in steady motion over each other when once the motion has commenced.** Corresponding to these two forces there will be two coefficients of friction. The coefficient of static friction and the coefficient of dynamic (or kinetic) friction. The coefficient of static friction is invariably greater than the coefficient of dynamic (or kinetic) friction.

Procedure :

Dynamic (sliding) Friction :

1. Adjust the table with a flat plate of glass on it so that the surface of the flat plate of glass is horizontal. Check it with the spirit level and by inserting pieces of paper/card board under the end which is lower.

(If you propose to slide the wooden block on the surface of table itself, make it horizontal.)

2. Make sure that the pulley is frictionless. If not, oil it.

3. Determine the least count and zero correction of the spring balance.

4. Find the correct weight of the given wooden block (W) and of the scale pan (P) separately.

5. Connect the hook of the wooden block with the help of a thread to the scale pan. Pass the thread over the frictionless pulley as shown in Fig. 9.1 so that the scale pan hangs freely in the air. The portion of the thread between the hook and the pulley may be horizontal.

6. Tap the glass top gently and adjust the weight w in the scale pan so that the block moves *slowly* and *continuously* along the whole length of the glass plate. Note the total weight in the pan including the weight of the pan *i.e.*, $P + w$. In this situation the average force of dynamic friction on the glass top is equal to $(P + w)$.

The motion of the block may have some jerks as the friction may be slightly greater at some portions of the glass top and less at others. Clean

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that portion by tissue or soft clean dry cloth and repeat the movement of the block.

7. Repeat the experiment at least six times by placing a weight of 20 g, 30 g, 40 g, 50 g, 100 g, 150 g etc. on the wooden block.

8. **Rolling Friction.** Next put *rollers e.g.,* round pencils, or glass rods slightly longer than the breadth of the glass top or nails with their heads cut off by a hacksaw etc., all along the glass surface and let the block move on them. Again find the force which moves the block slowly along the entire length of the glass top. In this case the light weight pan will have to be used and small weights (even milligram weights) will be needed to achieve proper adjustment, because the rolling friction is very small.

In fact, rolling friction depends on the objects placed below the block to roll on. If time permits find the rolling friction for mustard seeds or glass marbles or small ball bearings etc. placed below the block to roll on.

Repeat the experiment at least six times by placing a weight of 20 g, 30 g, 40 g, 50 g, 100 g etc., on the wooden block.

Observations and Calculations :

Least count of spring balance = ... g

Zero error of the spring balance = ... g

Weight of the wooden block Observed = ... g

Corrected = W = ... g

Weight of the scale pan Observed = ... g

Corrected = P = ... g

Dynamic (sliding) Friction :

S.No.	Weight on the block (x) in g	Weight in the pan (w) in g	Force of Dynamic (sliding) friction ($P + w$) in N
1.			
2.			
3.			
4.			
5.			
6.			
7.			

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Rolling Friction :

S.No.	Weight on the block (x) in g	Weight in the pan (w) in g	Force of rolling friction ($P + w$) in N
1.			
2.			
3.			
4.			
5.			
6.			
7.			

Precautions :

1. The pulley should be free from friction.

2. The glass surface should be clean, dry and horizontal.

3. The thread between the hook and the pulley should be *parallel* to the glass surface.

4. The pan should not touch any part of the table.

5. The glass plate should be very gently tapped.

6. It may happen that during the jerky continuous motion, the wooden block may get stuck up at some spot and may not move on tapping the horizontal surface. This spot is not sufficiently clean. Clean that spot by tissue or soft clean dry cloth and repeat the movement of the block.

Sources of Error :

1. The weights in the weight box may not be standard.

2. The pulley may not be frictionless.

3. The horizontal surface of the glass plate may not be equally rough everywhere.

Note. The position of the wooden block on the friction table, the direction of the wood fibres relative to it, and the moisture, all affect the magnitude of dynamic/rolling friction.

ORAL QUESTIONS

Q. 1. *What is friction ?*

Ans. When a body moves under the action of a certain force, the surface with which the body is in contact produces a counter force which resists the motion of the body by acting in the opposite direction. This resisting force is called friction.

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Q. 2. *What are its causes ?*

Ans. It is due to the roughness of the two surfaces. The two irregularities of surfaces in contact interlock. Friction depends upon the force with which the bodies are pressed against each other.

Q. 3. *What is limiting friction ?*

Ans. It is the maximum force which is called into play when one body moves over the surface of another body.

Q. 4. *What is coefficient of friction ?*

Ans. It is the ratio of the limiting friction (F) to the normal reaction (R) for the two surfaces in contact, *i.e.*, $\mu = \frac{F}{R}$.

Q. 5. *What are different kinds of friction ?*

Ans. Static friction ; sliding friction and rolling friction.

Q. 6. *Which is least of all ?*

Ans. Rolling friction.

Q. 7. *How will you reduce friction in your pulleys ?*

Ans. It is reduced by ball bearings wherein a rolling contact is substituted for a sliding contact as rolling friction is always less than the sliding friction and by lubrication.

Q. 8. *Is friction of any use in nature ?*

Ans. Yes ; walking should have been impossible without friction and skating all the more difficult. Nails and screws would not hold nor would the fibres of a rope hold together etc.

Q. 9. *Why friction in an evil ?*

Ans. Because work done by a machine, *i.e.*, output is always less than work done on it, *i.e.*, input and hence the efficiency of a machine is always less than 100%. This is because a part of the energy supplied to the machine is used up in over-coming friction between the various parts of the machine.

Q. 10. *How will you reduce friction ?*

Ans. By making the two surfaces smooth. By using ball bearings arrangement and by shaping the body in a stream line by using lubricants, etc., etc.

Q. 11. *What is static friction ?*

Ans. When a body is made to slide over the other, a force of friction comes into play in the opposite direction. As the applied force is increased, the opposing force also increases. This opposing force of friction is called static friction so long as the body does not move.

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Q. 12. *Is the static friction constant ?*

Ans. No. It increases with the applied force so long as the body does not move. It is a *self-adjusting* force.

Q. 13. *What is normal reaction ?*

Ans. When a body is placed over the surface of another body, the former gives action to the latter and the latter gives reaction to the former in the opposite direction. The magnitude of the reaction in the direction normal to the surface of the latter is called normal reaction.

Q. 14. *What are the laws of limiting friction ?*

Ans. (*i*) The magnitude of limiting friction between two surfaces is directly proportional to the normal reaction.

(*ii*) The magnitude of limiting friction is independent of the shape and area of the surfaces in contact so long as the normal reaction remains the same.

Q. 15. *Is the value of coefficient of friction same for all pairs of surfaces ?*

Ans. No ; the coefficient of friction is different for different pairs of surfaces.

Q. 16. *On what factors does the coefficient of friction depend ?*

Ans. It depends upon the nature and state of polish of the two surfaces in contact.

Q. 17. *What is dynamic friction or kinetic friction ?*

Ans. It is that force of friction which comes into play after the motion has started.

Q. 18. *What is rolling friction ?*

Ans. When a body rolls or tends to roll over the surface of another body, the resisting force called into play is known as the rolling friction.

Q. 19. *Which is greater ; static friction ; dynamic friction ; rolling friction ?*

Ans. Static friction is slightly greater than the dynamic friction whereas static friction and dynamic friction are very much greater than the rolling friction.

Q. 20. *How does rolling friction depend on the radius of the wheel ?*

Ans. The force of rolling friction varies inversely as the radius of the wheel.

Q. 21. *How does rolling friction depend upon rigidity of the two surfaces.*

Ans. It decreases as the rigidity of the two surfaces increases.

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Q. 22. *Why do we not get the same value of coefficient of friction for different observations ?*

Ans. Because the surface over which a body moves is not uniformly polished and so the friction is different at different points ; so the value of coefficient of friction also differs.

Q. 23. *What is angle of friction ?*

Ans. The angle which the resultant of normal reaction and force of limiting friction makes with the normal reaction is called angle of friction.

Q. 24. *What is the relation between angle of friction and coefficient of friction ?*

Ans. The tangent of the angle of friction is equal to the coefficient of friction, *i.e.*, $\mu = \tan \theta$ where μ = coefficient of friction and θ = angle of friction.

Q. 25. *Why do we oil the pulley ?*

Ans. The pulley is oiled so that the friction at the bearing is minimised and the pulley is free to rotate.

Q. 26. *What is the disadvantage if the pulley is not frictionless ?*

Ans. A part of the applied force is utilized in overcoming the friction of the pulley and thus the observed value of the coefficient of friction will be greater than the actual value.

Q. 27. *Why do we slip on a rainy day ?*

Ans. On a rainy day, water forms a thin layer the between shoe and the ground and the friction becomes very much less. Thus a person slips.

Q. 28. *Why should the thread from hook to pulley be horizontal ?*

Ans. If the thread is slightly raised, the surface of the body to which thread is attached may be raised and thus the surface may not be in contact with the lower surface.

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EXPERIMENT 10

To study the relationship between force of dynamic friction and normal reaction, between a block and a horizontal surface, and hence find the coefficient of friction.

Apparatus :

A table with a frictionless pulley fixed at one end (or an inclined plane apparatus with glass top and pulley), a flat plate of glass, of brass or of zinc, blocks of different materials with hooks, a scale pan, a weight box, spirit level, spring balance, a set of 5 × 200 g slotted weights, thread.

Theory :

Refer Fig. 9.1 and theory in Experiment 9.

Procedure :

1. Set the apparatus as in Experiment 9 and shown in Fig. 9.1.

Follow steps 1 to 6 in the procedure of Experiment 9 for dynamic friction.

Find the force of dynamic friction (P + *w*) first with the wooden block alone sliding on the horizontal glass surface.

Also find the corrected weight W of the block with the help of spring balance, which is equal to normal reaction (R) between the wooden block and the glass top.

2. Next place one slotted weight (200 g) on the wooden block and measure the force of dynamic friction as well as normal reaction.

In this manner make such two measurements with various weights placed on the wooden block.

3. Plot a graph taking normal reaction (R) along X-axis and the dynamic friction (F) = P + *w* along Y-axis. The graph will be a straight line upto a certain limit (Fig. 10.1).

(Draw a straight line with a ruler which best fits the points marked on the graph paper to represent your experimental data because measurement of force of dynamic friction is not a precise measurement and your data may not be able to distinguish between a straight line graph and a curved graph).

4. By covering the table with a flat plate of brass or of zinc and using blocks of different materials, the force of dynamic friction between several different pairs of surfaces can be determined.

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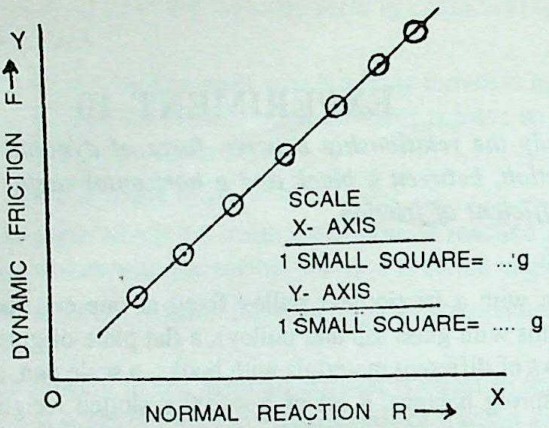

Fig. 10.1

Notes. You may have to make a judicious choice of the size of the block and the set of slotted weights for this experiment. If the block is too light, its force of dynamic friction may even be less than the weight of empty scale pan and you may not be able to take an observation with block alone. Similarly, the maximum normal reaction, with which you work by placing the entire set of slotted weights on the block should not be so large that its force of dynamic friction is larger than the force obtained by placing all the weights of the weight box on the pan.

2. If the slow continuous motion of the block on the glass surface is too jerky, clean the glass surface by rubbing it briskly with a clean soft dry cloth. If oil spots are seen on it, clean by soap solution.

It is essential for consistent results that the surface of any one plate shall be in a **uniform state of polish all over.** If this is not the case, the experiment must be carried over so that the portion of the lower surface moved over is always the same. This is done by marking a line on the fixed surface and starting the block always from that line.

3. It is also essential that the surfaces be in the same condition in all the observations with a given pair of surfaces. If the surfaces are pressed together before applying the force, the coefficient of friction will be changed to some extent. If moisture condenses on the surfaces, the coefficient of friction will be changed entirely.

Observations and Calculations :

Least count of the spring balance = ... g

Zero error of the spring balance = ... g

Weight of the block Observed = ... g

Corrected = W = ... g

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Weight of the scale pan Observed = ... g

Corrected = P = ... g

S.No.	Weight on the blcok (x) in g	Weight in the pan (w) in g	Normal Reaction R = (W + x) in g	Force of dynamic friction F = (P+w) in g	Coefficient of dynamic friction $\mu = \frac{F}{R}$
1.					
2.					
3.					
4.					
5.					
6.					
7.					
8.					
				Mean value of μ =	

From the graph :

Force of dynamic friction (F) = ... g

Normal Reaction (R) = ... g

$\therefore$ Coefficient of dynamic friction $\mu = \frac{F}{R}$ =.....

Result :

(*i*) Since the graph between normal reaction (R) and the force of dynamic friction (F) is a straight line, therefore, $F \propto R$ for a particular pair of surfaces in contact.

(*ii*) The ratio $\frac{F}{R}$ is a constant and is called the coefficient of dynamic friction (μ) for a particular pair of surfaces in contact.

Precautions :

Same as in Experiment 9.

Sources of Error :

Same as in Experiment 9.

ORAL QUESTIONS

Same as in Experiment 9.

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EXPERIMENT 11

(a) To find the time-period of a simple pendulum and hence find the value of g i.e., acceleration due to gravity at a place.

(b) Draw a graph between l v/s t and l v/s t^2 and study which is better where l is the length of simple pendulum and t is the time period.

(c) To determine the length of the second's pendulum from the graph l v/s t^2.

Apparatus :

Metallic bob with hook, clamp stand ; two split pieces of cork ; fine cotton thread about 200 cm in length ; Vernier callipers ; stop-watch or stop-clock ; metre-rod ; stand and a piece of chalk.

Theory :

An ideal simple pendulum consists of a heavy particle suspended by a weightless, inextensible and perfectly flexible string from a point about which it can vibrate without friction. But as these conditions cannot be achieved in practice, a metallic bob suspended by means of five cotton thread constitutes a simple pendulum.

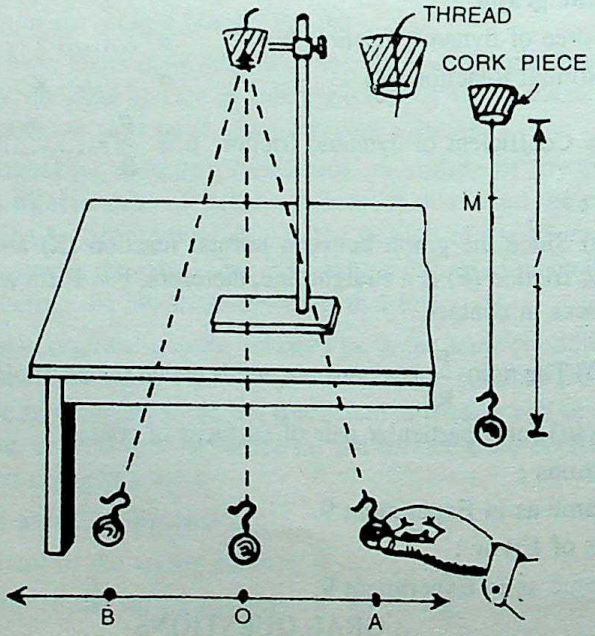

Fig. 11.1. Simple Pendulum.

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As the bob is displaced from its mean position, it moves to and fro about this position with simple harmonic motion (S.H.M.). The time taken to complete one vibration (Time Period t) is given by

$$t = 2\pi\sqrt{\frac{l}{g}}$$

where l = effective length of the pendulum, *i.e.*, length of thread + radius of the bob.

and g = Acceleration due to gravity at a place.

$$g = 4\pi^2 \frac{l}{t^2}$$

At a given place, 'g' is constant

$$\therefore \quad \frac{l}{t^2} = \text{constant}$$

or graph between l and t^2 is a straight line.

A **Second's Pendulum** is that Pendulum whose length is such that it completes one vibration in 2 seconds.

Procedure :

(*i*) Find the vernier constant and zero error of vernier callipers. Determine diameter and hence radius of the bob with the help of vernier callipers as explained in Expt. (1).

(*ii*) Tie the bob to one end of the given cotton thread (150 cm). Pass other end of the thread through the two half pieces of a cork and hold the cork firmly in the clamp-stand. See that cut of the cork is at right angles to the edge of the table.

(*iii*) Place the stand on the table as shown in Fig. (11.1) above in such a way that bob is at a distance of one to two cm above the ground. Mark two lines with a piece of chalk just below the bob, one of the lines being parallel to the edge of the table and second perpendicular to it. Adjust the stand so that the bob lies exactly above the point of intersection of the two lines.

Mark two points A and B on either side of the point of intersection and at a distance of 2 cm from it as shown in the diagram. (Fig. 11.1).

(*iv*) Put an ink Mark M with your pen on the thread at a distance of 80 cm from the centre of gravity (c.g.) of the bob. Put six more marks on the thread each at a distance of 10 cm from the previous one. This means that the new marks are at distances of 90, 100, 110, 120, 130, 140 cm from the c.g. of the bob.

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Put the 140 cm mark just at the lower surface of the cork *i.e.*, at the point of suspension by suitably pulling the thread through the cork piece. Now adjust the position of the clamp on the stand in such a way that the bob keeps a height of 1 to 2 cm from the ground and exactly above the point of intersection of the two lines perpendicular to each other.

(*v*) Take the bob along the line AB distance of 2 cm on either side of the point of intersection and release it. The pendulum begins to oscillate. See that it executes linear vibrations, *i.e.*, it oscillates along the straight line and not along an elliptical or circular path. **Also see that the pendulum does not start spinning. Now examine the stop clock/watch and find out its least count. Also determine its zero error if any.**

If the vibrations are linear and the amplitude of vibration is small, after few vibrations, start the stop watch or clock when the pendulum just passes through 0, the mean position of the pendulum towards any side say A and count zero. When it again passes through '0' in the same direction, *i.e.*, towards A, count 1, 2, 3 and so on upto 20 in this way and stop the watch when the last vibration is just completed. Note the time for 20 vibrations upto the fraction of a second. Repeat three times without stopping the vibration of the bob and take the mean time. Convert this time into seconds and divide it by the number of vibrations, *i.e.*, 20 to get the periodic time (t) of the pendulum for this length.

(*vi*) Next, reduce the length by 10 cm by pulling the thread up after slightly loosening the clamp. Also lower the clamp to keep the bob near the floor as before and take the time period for this length. In this way repeat the experiment at least six times by reducing length.

See that at least four readings should be taken when the length of the thread is more than one metre and two readings when less than 100 cm.

Calculate the vlaue of l/t^2 for each observation and take the mean. Find the value of 'g' by multiplying this mean by 4π.

(*vii*) *Determination of Length of Second's Pendulum from Graph.* Plot $l - t^2$ graph using the value of 'l' as abscissa and the corresponding value of t^2 as ordinate with suitable scales and with the least value as origin. This will be a straight line as shown in Fig. 11.2.

A simple pendulum whose time period is 2 seconds is called a second's Pendulum.

Thus if t = 2 sec ; t^2 = 4 sec^2. Hence corresponding to t^2 = 4 along the y-axis, draw a horizontal line which intersects the graph at a point. Draw a vertical line through point of intersection and read the value of 'l', which is the required length of second's pendulum.

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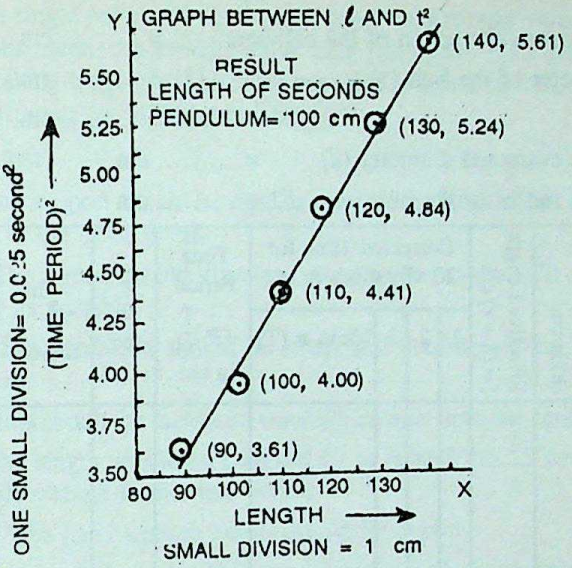

Fig. 11.2

(*viii*) Plot *l*–*t* graph, taking *l* along *x*-axis and *t* along *y*-axis as shown in Fig. 11.3. The graph will be a curved one.

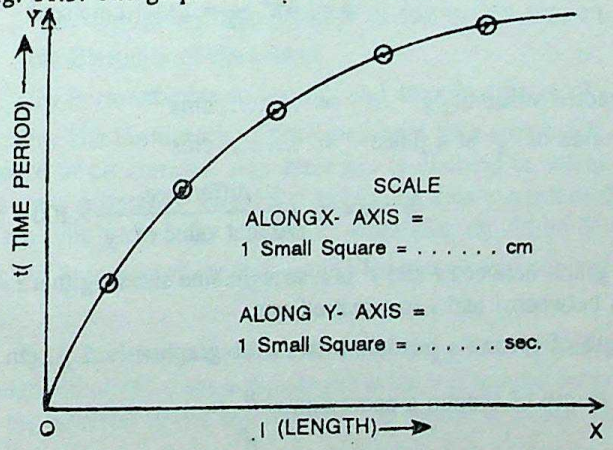

Fig. 11.3. Graph l v/s t

Observations :

Least count of stop watch = ... s
Zero error of stop watch = ... s
Vernier constant of the callipers (V.C.) = ... cm
Zero error of the callipers (1) = ... cm
(2) = ... cm
(3) = ... cm

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Mean zero correction of the callipers = ... cm

Diameter of the bob (1) .....cm (2) = ... cm

Mean = ... cm

Mean corrected diameter (d) = ... cm

Mean radius of the bob= $r = d/2$ = ... cm

S. No.	Length of the thread with hook (h) in cm	Effective Length $l = (h + r)$ cm	Corrected Time for 20 vibrations in sec.				Time Period $t = \frac{T}{20}$ in sec.	t^2 in sec^2	$\frac{l}{t^2}$ in cm/sec^2	Mean $\frac{l}{t^2}$ in cm/sec^2
			1	2	3	Mean = (T)				
1.										
2.										
3.										
.....										
8										

Calculations :

$$\therefore \quad g = 4\pi^2 \frac{l}{t^2} = \ldots\ldots\ldots cm/sec^2$$

Result :

(a) Corrected value of 'g' = ... cms^{-2}

Actual value of 'g' at a place = ... cms^{-2}

$$\therefore \quad \% \text{ error} = \frac{\text{difference}}{\text{Actual value of '}g\text{'}} \times 100$$

(b) The graph between l and t^2 is a straight line showing that $l \propto t^2$ and the graph between l and t is a curved one.

(c) Length of second's pendulum from the graph = ... cm

Correct length of second's pendulum = $\frac{g}{\pi^2}$ = ... cm

$$\% \text{ error} = \frac{\text{difference}}{\text{correct value}} \times 100$$

Discussion :

(d) The graph between l *v/s* t^2 is **better** than the graph between l *v/s* t. This is because the slope for a graph between l *v/s* t^2 (which is a straight line) is the **same** for all the points on it while *this is not so* for a graph between l *v/s* t (which is a curved one). Whereas the calculation of

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'g' using a single point on l v/s t^2 graph gives the **average value** of all the observations taken, the average value of g from the l v/s t graph can be found by taking **large number of points** on it as it is a curved one and the slope is different for different points.

Precautions :

1. The support should be rigid and the lower faces of the cork pieces should be in the same plane.

2. The thread should vibrate at right angles to the split and should be as long as possible.

3. The amplitude should be small and the bob should move in a straight line.

4. Time should be measured carefully correct upto the smallest value.

5. The length should be changed by at least 10 to 15 cm to have a considerable change in the time period.

6. A free hand smooth graph should be drawn.

7. The experiment should be performed at a place where disturbance due to air is minimum.

Sources of Error :

(*i*) Non-rigidity and vibration of suspension support.

(*ii*) Elasticity of the thread.

(*iii*) Personal error in starting and stopping the clock.

(*iv*) The inaccuracy of time measured by a stop clock or watch and presence of air currents. Any error in t is doubled in calculation of t. To measure 't' accurately the clock may be compared to a standard chronometer and the time for a large number of vibrations should be determined.

(*v*) Spinning of the bob cannot be completely avoided.

Exercises

Q. 1. *Prove by experiment that the time period of a simple pendulum is independent of (a) the amlitude provided it is not too large (b) the mass and the material of the bob, and (c) the nature of string used.*

Q. 2. *Find the period of a pendulum 5 metres long.*

Hint : Find the mean value of $\frac{l}{t^2}$ for some suitable lengths.

Let it be 'c' ; then $\frac{l}{t^2} = c$ or $t^2 = \frac{l}{c}$ or $t = \sqrt{\frac{l}{c}}$

By substituting the value of 'c' and $l = 500$ cm, 't' may be calculated.

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ORAL QUESTIONS

Q. 1. *Distinguish between 'g' and 'G'. Give their units.*

Ans. 'g' is the acceleration due to gravity caused due to force of attraction due to earth. 'G' is the universal gravitational constant and it is defined as the force of attraction between two bodies of unit mass each separated by a unit distance between them.

	C.G.S. System	S.I. System
'g'	cm/s^2	m/s^2
'G'	dynes cm^2/g^2	$N\text{-}m^2/kg^2$

Q. 2. *Is there any relation between 'g' and 'G' ? What are the values of 'g' and 'G' ?*

Ans. $g = \frac{GM}{R^2}$ where M = mass of the earth

R = Radius of the earth ; $g = 980\ cm/s^2$ or $9.8\ ms^{-2}$

G = 6.67×10^{-8} dynes cm^2/g^2 or $6.67 \times 10^{-11}\ Nm^2/kg^2$

Q. 3. *What is the difference between gravity and acceleration due to gravity ?*

Ans. Gravity is the force with which the body is attracted towards the centre of the earth while acceleration due to gravity is the acceleration produced due to gravity.

Q. 4. *How does 'g' vary with height; depth or due to rotation of the earth about its axis ?*

Ans. It decreases with height ; with depth and due to rotation of the earth.

Q. 5. *How does 'g' vary from place-to-place on the surface of earth ?*

Ans. It is minimum at the equator, goes on increasing as we go towards the poles and is maximum at the poles.

Q. 6. *What will be the weight of the body at the centre of the earth ?*

Ans. The weight of the body will be zero there because 'g' is zero at the centre of the earth.

Q. 7. *Is 'g' a scalar quantity or a vector quantity ?*

Ans. It is a vector quantity.

Q. 8. *What will happen if 'g' becomes zero on the surface of the earth ?*

Ans. No body shall have any weight and all the bodies will fly away in the space.

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Q. 9. *What is a simple pendulum ? Who discovered it ?*

Ans. A simple pendulum is defined as a heavy mass suspended by a weightless, inextensible and perfectly flexible string. Galileo discovered it.

Q. 10. *Can you have a simple pendulum strictly according to its definition ?*

Ans. No ; as it is impossible to have a weightless, inextensible and perfectly flexible string.

A heavy mass suspended by a cotton thread is the nearest approach to a simple pendulum.

Q. 11. *Why do we use a heavy bob ? Why should the bob be smaller in size ?*

Ans. We use a heavy bob so that the restoring force trying to bring the bob back to its mean position may be large enough to overcome the resistance due to air.

Bigger the size, the more will be resistance due to air.

Q. 12. *What is effective length of a Pendulum ?*

Ans. It is the total length from the point of suspension to the centre of gravity of the bob.

Q. 13. *Can we use a conical or cylindrical bob instead of spherical one ?*

Ans. Yes ; it can be used but spherical bob is always preferred because it is easier to locate its centre of gravity.

Q. 14. *Define Simple Harmonic Motion.*

Ans. It is that periodic motion in which acceleration is proportional to the displacement and is always directed towards the mean position.

Q. 15. *What is vibration ?*

Ans. By a vibration we mean the motion of the bob from the mean position to one extreme position, back to the mean position, then to the other extreme position and back again to the mean position.

Q. 16. *What is time period ?*

Ans. It is the time taken by a body to complete one vibration.

Q. 17. *Define Amplitude.*

Ans. It is the displacement of the bob on either side of its mean position.

Q. 18. *What will happen if a hole is bored through the earth right to the other end and a body by dropped into it ?*

Ans. It will execute S.H.M.

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Q. 19. *What is the formula for the time period of a Simple Pendulum ?*

Ans. $t = 2\pi\sqrt{\frac{l}{g}}$ where t = time period

l = effective length of the pendulum

g = Acc. due to gravity.

Q. 20. *Why should the amplitude be small ?*

Ans. Because the formula for the time period has been derived by assuming $\sin\theta \approx \theta$ which is true only for small amplitude.

Q. 21. *What is second's pendulum ?*

Ans. A pendulum whose time period is two seconds is called second's pendulum.

Q. 22. *Does the time period of a simple pendulum depend upon mass, size and material of the bob ?*

Ans. No ; the time period is independent of the mass, size and nature of the material of the bob.

Q. 23. *What are the positions where bob has maximum velocity and acceleration ?*

Ans. The velocity is maximum at the mean position and acceleration is maximum at the extreme position.

Q. 24. *What is an isochronous motion ?*

Ans. It is that motion in which the time period remains the same although the amplitude goes on decreasing.

Q. 25. *Why does the amplitude decrease with time ?*

Ans. Due to resistance of air and friction at the point of support.

Q. 26. *Does the law of conservation of energy hold good during the motion of a simple pendulum ?*

Ans. Yes, it holds good.

Q. 27. *What will happen if the bob is made to oscillate in water ?*

Ans. The time period will increase as the effective value of 'g' decreases due to upward thrust of water.

Q. 28. *What will happen if the bob vibrates in vacuum ?*

Ans. The time period decreases as the value of 'g' increases because in vacuum there will be no effect of buoyancy of air.

Q. 29. *Why we start taking time period after it has completed some vibrations ?*

Ans. The first few vibrations are supposed to be forced vibrations. Thus the bob will not have its free time period during these few vibrations.

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Q. 30. *What happens if the bob has rotatory motion along with the translatory motion ?*

Ans. There will be twists in the thread due to rotatory motion which will affect the time period.

Q. 31. *Why do the clocks go fast in winter and slow in summer ?*

Ans. Because the length of the pendulum decreases in winter, so the time period decreases and thus the clocks go fast in winter. In summer their length increases and thus the time period increases resulting in the slow running of the clock.

Q. 32. *Why are the pendulums of good clocks made of invar ?*

Ans. Because invar (an alloy containing 64% of iron and 36% of nickel) has a very small coefficient of expansion.

Q. 33. *What is personal error ?*

Ans. The stop clock may not be started or stopped at the correct time, thus introducing on error in noting down the time period.

Q. 34. *What is an inaccessible pendulum ?*

Ans. It is that pendulum whose point of suspension is so high that its length cannot be measured directly.

Q. 35. *What type of graphs we get between (a) l and t^2, (b) l and t?*

Ans. (*a*) Straight line, (*b*) Parabolic curve.

Q. 36. *What is the principle underlying measurement of time ?*

Ans. In principle any process which repeats itself after regular intervals of time can be used for measurement time.

Q. 37. *Upon what factor does the pulse rate of a human being depend ?*

Ans. Pulse rate depends upon the mental and physical conditions and it varies from one individual to another.

Q. 38. *How could pulse rate be used for measuring time ? Is it a reliable method ?*

Ans. By calculating one's own pulse beat. Since pulse rate varies from one individual to other and it depends upon the mental and physical conditions so as such a lot of subjectivity creeps into the measurement.

Hence it is not a reliable method.

□□

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EXPERIMENT 12

To plot a graph between the distance of the knife edges from the centre of gravity and the time period of a bar pendulum. From the graph find

(a) the acceleration due to gravity at*.....

(b) the radius of gyration of the bar about an axis passing through the centre of gravity and perpendicular to its plane.

Apparatus Required :

The bar pendulum, knife-edge for suspending the pendulum, metre scale, spirit level and a stop-watch.

Description of the Apparatus

A simple form of compound pendulum designed by D. Owen in 1939 is shown in the accompanying Fig. 12.1. It consists of a metallic bar nearly a metre long, in which a series of circular holes of nearly 5 mm diameter are bored at equal distances (nearly 2 cm), along its length. With the help of these holes the bar can be suspended from a knife-edge and made to oscillate. The knife-edge is fixed in a platform supported on three screws ; the hinder one of which is adjustable, thereby the platform can be made horizontal.

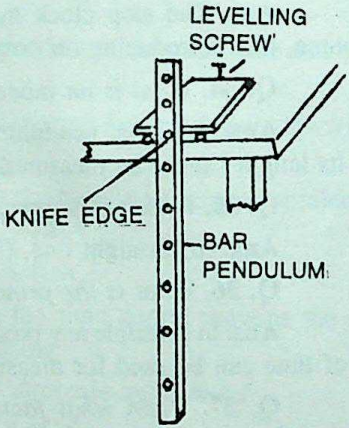

Fig. 12.1. Bar pendulum

Formula Employed :

The value of g can be calculated from any of the following formula :

$$g = \frac{4\pi}{T_0^2} \cdot (2k) \qquad \ldots(1)$$

The minimum time-period T_0, and $2k$ (where k is the radius of gyration of the bar about an axis passing through its centre of gravity and parallel to the axis of rotation) can be read from the graph.

Also, $$g = 4\pi^2 \cdot \frac{h_1 + h_2}{T^2} \qquad \ldots(2)$$

*Name the place where the experiment is being conducted.

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where T = time-period

$h_1 + h_2$ = length of the equivalent simple pendulum.

Both these quantities can be read off from the graph.

The radius of gyration can also be calculated from the formula :

$$k = \sqrt{h_1 \cdot h_2} \qquad \ldots(3)$$

Principle and Theory of the Experiment

If the compound pendulum be allowed to oscillate about a horizontal knife-edge passing successively through each hole, and a graph be plotted taking the periods of oscillation as ordinates and corresponding distances of the axis of suspension from the C.G. of the bar as abscissae, a graph of the type shown below (Fig. 12.2) will be obtained :

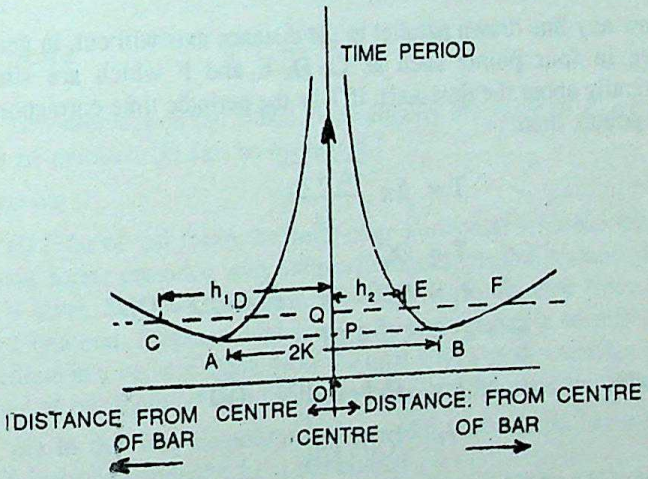

Fig. 12.2. T–h graph for a compound pendulum.

Now we know that the time-period T of a compound pendulum is given by :

$$T = 2\pi \cdot \sqrt{\frac{k^2 + h^2}{hg}}$$

where h is the distance of its centre of gravity from the point of suspension, and k is the radius of gyration about a parallel axis passing through the centre of gravity.

When the axis of suspension passes through the centre of gravity, the periodic time becomes infinitely great. If the axis is at an infinite distance the periodic time is again infinite. Consequently there must be some

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intermediate position for which the periodic time is a minimum. Now T will be a minimum when $\frac{k^2+h^2}{h}$ is minimum.

But $$\frac{k^2+h^2}{h} = \frac{(k-h)^2+2kh}{h} = \frac{(k-h)^2}{h} + 2k$$

This is clearly a minimum when $k = h$.

Thus the minimum time-period

$$T_0 = 2\pi\sqrt{\frac{k^2+k^2}{kg}} = 2\pi\sqrt{\frac{2k}{g}} \qquad \ldots(1)$$

From the graph, $T_0 = OP$

and $$2k = AB \qquad \ldots(2)$$

Now any line drawn parallel to the distance axis will cut, in general, the curve in four points such as C, D, E and F which are situated symmetrically about the time-axis. If T be the periodic time corresponding to these points, then

$$T = 2\pi\sqrt{\frac{h_1+h_2}{g}} \qquad \ldots(3)$$

where $T = OQ$

$h_1 = QC = QF \quad h_2 = QD = QE$

or $h_1 + h_2 = CE = DF$

Again $$k = \sqrt{h_1 h_2} = \sqrt{QC \,.\, QD}$$

$$= \sqrt{QF \,.\, QE} \qquad \ldots(4)$$

From (1) and (3) we can calculate the value of g, while from (2) and (4) we can obtain the value of k.

[**Note**—An alternative method to find the mean value of g and k is as follows :

The equation $T = 2\pi\sqrt{\frac{k^2+h^2}{hg}}$ can be written as

$$T^2h = \frac{4\pi^2}{g} \,.\, h^2 + \frac{4\pi^2}{g} k^2$$

By plotting T^2h against h^2, a curve (straight line) as shown in Fig. 12.3 is obtained. The slope of this curve is given by

$$\tan\theta = \frac{4\pi^2}{g}$$

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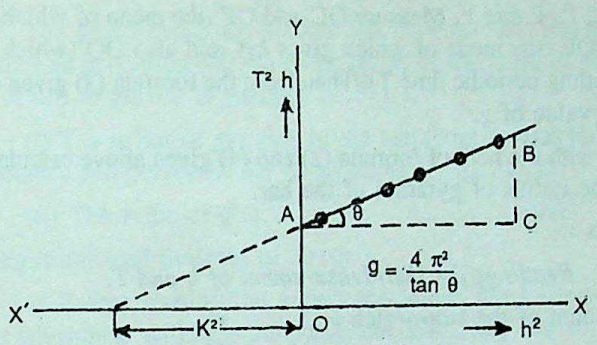

Fig. 12.3

Hence $$g = \frac{4\pi^2}{\tan\theta}$$

The intercept on the x-axis gives directly the value of k^2 whence the radius of gyration (k) can be evaluated.]

Procedure :

(*i*) First of all make the knife-edge horizontal with the help of the levelling screw provided with the platform and test the horizontality with a spirit level. Suspend the pendulum about the knife-edge from the hole nearest one end. Displace the bar slightly and release it so that it begins to oscillate in a vertical plane. Note the time with a stop-watch for a known number of oscillations* and from this calculate the periodic time.

(*ii*) In this way determine the periodic time of the bar when it is successively suspended** from the holes.

(*iii*) Now with the help of a metre scale measure the distance of the positions of the knife-edge from the C.G.† of the bar. Then plot a graph between the periodic times (T) and the corresponding distances (h) of the points of suspension from the C.G. of the bar.

(*iv*) Join A and B (See Fig. 12.2). The line AB cuts the T-axis at P. The abscissa of P gives the position of the centre of gravity of the bar.

*To facilitate the counting of oscillations correctly, place a pointer (or make a mark on the wall behind the bar) coincident with the mean position of the pendulum.

**As the pendulum is made to oscillate from the holes which are near to the centre, the time period increases, hence very few oscillations can be timed in these positions. When the bar is suspended from the central hole it may not even be set to vibration, since its weight does not have any moment about the fulcrum which now passes through the centre of gravity of the bar.

†Note the position of the C.G. by balancing the bar on a sharp wedge.

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Draw any line CDEF perpendicular to the T-axis and cutting the curve in four points C, D, E and F. Measure QC and QF (the mean of which gives h_1), QD and QE (the mean of which gives h_2), and also OQ (which gives the corresponding periodic time T). Then from the formula (3) given above calculate the value of g.

Again, with the help of formula (2) and (4) given above calculate the value of k, the radius of gyration of the bar.

Observations :

Readings for the Measurement of h and T.

Least count of the stop-watch = ... s

No. of the hole	Distance of hole from the C.G. (h)	No. of Oscillations	Time taken	Periodic Time (T)
1		25 25 25 25	..... s ..... s ..... s ..... s	..... s
2 ⋮ ⋮				

Calculations :

From the graph

(*i*) QC = ... cm, QF = ... cm ∴ Mean h_1 = ... cm

QD = ... cm, QE = ... cm ∴ Mean h_2 = ... cm

∴ $h_1 + h_2$ = ... cm

Also T = OQ = ... s

∴ $g = 4\pi^2 \cdot \frac{h_1 + h_2}{T^2}$ = ... cm/s^2

(*ii*) $2k$ = AB = ... cm

T_0 = OP = ... s

∴ $g = 4\pi^2 \cdot \frac{2k}{T^2}$ = ... cm/s^2

(*iii*) $k = \sqrt{h_1 h_2}$ = ... cm

Also $k = \frac{1}{2}$AB =..... cm

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Result :

The graph depicting the relation between the time-period (T) of a compound pendulum and the distance (h) of the point of suspension from the centre of gravity is attached herewith.

(i) The radius of gyration of the bar about an axis through its centre of gravity and perpendicular to its plane = ... cm

(ii) The value of g at ..... = ... cm/s^2

Precautions and Sources of Error :

1. Before starting the experiment make the knife-edge horizontal. This adjustment will keep the pendulum oscillating in a vertical plane, and secondly the bar shall not tend to slip off the knife-edge during oscillations.

2. In the theoretical deduction of the formula it has been assumed that $\sin\theta \approx \theta$ where θ is the angular deflection of the bar. Hence to satisfy this condition the bar should not be displaced more than 5° from its mean position.

3. To get very exact points on the curve in the vicinity of the minimum period, the time should be observed very carefully. Try to note the time for 100 oscillations except for points very close to the centre of gravity of the bar, where, due to large time periods, few oscillations can be timed.

4. Before taking observations see that the pendulum is oscillating in the vertical plane only, and that all other irregular motions, if any, have subsided.

5. The curves on the graph should be smoothly drawn.

6. The manner of observing the oscillations is far from satisfactory; secondly the time perid has not been corrected for (i) finite arc of swing, (ii) air effects, (iii) curvature of knife-edge, and (iv) yielding of support, hence the result is not free from errors due to these causes.

ORAL QUESTIONS

(Also read Oral Questions in Expt. 11)

Q. 1. *What is a compound pendulum ?*

Ans. A compound pendulum is just a rigid body capable of oscillating freely about a horizontal axis passing through it.

Q. 2. *If any rigid body can serve the purpose of a compound pendulum, then why this particular shape of your instrument (bar or metre scale) ?*

Ans. There is one serious disadvantage of a compound pendulum. Due to its vibration some air is dragged with it, thus increasing its effective mass and hence its moment of inertia. But it has been shown by Bessel that

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if it be of a form symmetrical about the centre of geometrical shape*, this error is automatically eliminated. This is one of the reasons of using a compound pendulum in the shape of a bar or a metre-scale.

Secondly this bar or metre-scale has been provided with circular holes situated at equal distances on either side of its centre of gravity. By slipping any hole on to a horizontal knife-edge, the bar can be made to oscillate about it in the vertical plane. Thus we can study the variation of the time period with the distance of the axis of rotation from the centre of gravity of the bar.

Q. 3. *Does the time period vary ? How does it vary ?*

Ans. Yes. It does vary. The time-period of the pendulum is given by the formula

$$T = 2\pi \sqrt{\frac{\frac{k^2}{h} + h}{g}}$$

where k is the radius of gyration of the bar and h is the distance of the point of suspension from the centre of gravity of the bar.

Thus, if a graph is plotted between T and h, its nature is as shown in Fig. 12.2. It is clear from the graph that there are two values of h on either side of the C.G. which give the same value of T.

Q. 4. *Explain what will happen if the pendulum is made to oscillate about its C.G. ?*

Ans. In the formula for T if we put $h = 0$ (since the axis of rotation passes through the C.G.), the time-period assumes an infinite value. This can also be visualized from the fact that under this circumstance the weight of the pendulum has no component about the fulcrum, hence, it cannot be set into vibration, or, which is the same thing the time-period becomes infinite.

Q. 5. *So, according to you, there are two points on either side of the C.G. about which the periods are equal. Name and define these points.*

Ans. One point is known as the *centre of suspension*, which can be defined as that point at which the axis of rotation (or the fulcrum) intersects the plane of oscillation of the pendulum.

The second point, known as *the centre of oscillation*, is a point situated on the other side of the C.G. and lying on the line joining the point of oscillation to the C.G. and distant $\frac{k^2}{l}$ from it (the C.G.).

*Students should bear in mind that the centre of gravity is a mathematical point in the geometrical shape of a body is not the same thing as its centre of gravity.

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Q. 6. *Now tell me one thing. When g can be determined with a simple pendulum, what is the advantage of using a compound pendulum ?*

Ans. There are several reasons for this :

(*i*) Whereas a simple pendulum is just an ideal conception, not realisable in actual practice in the case of a compound pendulum the length of an equivalent simple pendulum and hence the value of *g* can be easily and accurately determined.

(*ii*) The compound pendulum vibrates as a whole, there being no lag between the bob and the string.

(*iii*) In the case of a compound pendulum, the length to be measured is clearly defined and hence can be easily and accurately measured, whereas in the case of a simple pendulum, the point of suspension and the C.G. of the bob are both, more or less indefinite points, and hence its true length can hardly be expected to be accurately determined.

(*iv*) Since the compound pendulum has a large mass, it continues to vibrate for a long time, thus its periodic time can be determined with sufficient accuracy. In a simple pendulum the oscillations cease much sooner, since the mass of the bob is comparatively much less. Hence the accuracy attained in the determination of the time-period is not to the same degree as in the case of the compound pendulum.

(*v*) In the case of a simple pendulum, the string slightly slackens at the extremity of its vibration, but the compound pendulum being a rigid body, no such thing happens in this case.

Q. 7. *So it means that this is an ideal pendulum and there are no sources of error in your experiment. Is it not ?*

Ans. No, this is not the meaning of the statement. There are several sources of error in this experiment.

Q. 8. *What are they ?*

Ans. (*i*) **Finite Amplitude of Swing.** The expression for the time-period has been obtained on the assumption that the angular displacement of the pendulum is vanishingly small. This is far from truth in actual practice.

(*ii*) **Air Effects.** The presence of air in the medium in which the pendulum swings affects its vibrations in three ways :

Firstly, due to the buoyancy of the air there is a slight decrease in the weight of the pendulum, thereby affecting the time-period.

Secondly, some air is dragged alongwith the pendulum. This increases the effective mass of the pendulum, thereby increasing its moment of inertia.

Thirdly, due to the viscosity of the medium, the motion of the pendulum is resisted. Consequently its time-period is affected.

(*iii*) **Non-rigidity of the support.** Due to a force being applied by

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the vibrating pendulum, the support may yield. This will obviously affect the time-period of the pendulum.

(*iv*) **Curvature of the knife edge.** If the knife edge is not quite sharp but rounded, an error is introduced in the time-period.

(*v*) **Change of temperature during experiment.** This results in a corresponding change in the length of the pendulum, and hence in its time-period.

Q. 9. *It means that due to the presence of these sources of error, the value of g cannot be accurately determined. Is it right ?*

Ans. No, this is not exactly so. The corrections due to these causes have been theoretically studied and mathematical formulae have been deduced for the same. By applying these corrections accurate value of g can be obtained.

Q. 10. *All right. How will you find the value of g from these observations ?*

Ans. I will draw a graph between T and h (Fig. 12.2) and shall get two curves of this type. Then I shall draw a horizontal line CDQEF. From this I shall read h_1 (= QC or QF) and h_2 (= QD or QE). Noting the corresponding time-period T, I shall get the value of g with the help of the formula.

Q. 11. *Is there any other way of calculating g with this graph ?*

Ans. Yes. If we note the minimum time period T_0, then $g = \dfrac{4\pi^2}{T_0^2} \cdot 2k$

where $2k$ is the distance between the two minima points lying on the two branches of the curve.

Q. 12. *Can you get a straight line graph with these readings ?*

Ans. Yes. The formula for the compound pendulum is

$$T = 2\pi \sqrt{\frac{\frac{k^2}{h} + h}{g}}$$

This can be put in form

$$T^2 h = \frac{4\pi^2}{g} \cdot h^2 + \frac{4\pi^2}{g} k^2$$

or

$$y = \frac{4\pi^2}{g} \cdot x + \frac{4\pi^2}{g} k^2$$

which is of the form $y = mx + c$. Thus by drawing a graph between T^2h and h^2, we get a straight line (Fig. 12.3).

Q. 13. *Can you get the value of g and k from this graph ?*

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Ans. Yes. The slope θ of the straight line is given by $\tan\theta = \frac{4\pi^2}{g}$. From this g can be calculated. Again, the intercept of this line on the x-axis gives k^2 and hence k.

Q. 14. *Explain in a simple manner what do you understand from the expression "Moment of Inertia of a body" ?*

Ans. Every body maintains or tends to maintain its state of rest or of uniform motion in a straight line. If we wish to change this state, the body offers a kind of passive resistance to the agent moving it. This passive resistance or inertness of bodies is called **Inertia** and is proportional to the mass of the body. This is the case of a translational motion. In the case of a rotatory motion, however, the resistance offered by a body does not depend simply on its mass. The sluggishness of a rotating body is called rotational inertia or **moment of inertia.** Unlike the simple inertia of a body undergoing a motion of translation, the rotational inertia depends upon the total mass of the body and the distances of various portions of the body from the axis about which the body rotates.

Thus, in rotatory motion the quantity known as moment of inertia plays the same role as mass does in a translatory motion.

Q. 15. *How is the moment of inertia mathematically expressed ?*

Ans. If 'm' is the mass of the particle whose distance from the axis of rotation is r, then moment of inertia of the particle is measured by the quantity mr^2. Hence the moment of inertia of the whole body is expressed by Σmr^2.

Q. 16. *What is the significance of the symbol Σ (sigma) used in the expression $\Sigma\, mr^2$?*

Ans. The symbol Σ (sigma) stands for summation of quantities. If the particles constituting the body have masses $m_1, m_2, m_3, \ldots, m_n$ and their corresponding distances from the axis of rotation be $r_1, r_2, r_3, \ldots, r_n$, then the moment of inertia of the constituent particles, that is

$$I = m_1r_1^2 + m_2r_2^2 + \ldots + m_nr_n^2$$

which can be (abbreviated as) $= \Sigma mr^2$

Q. 17. *What is the significance of the words "Moment of Inertia" ?*

Ans. A rigid body is set rotating by a 'torque' which is simply "the moment of a couple". The body, in its turn, offers a passive resistance which is known as the "Inertial reaction" of the body. This should also be a torque, since only a couple can counteract a couple. It is for this reason that this inertial reaction is designated as 'Moment of Inertia'.

Q. 18. *Can you give a clear cut definition of Moment of Inertia ?*

Ans. Yes. The moment of Inertia of a body about an axis is the sum of the products mr^2 taken for all the particles composing the body, where m is the mass of a particle, and r is its distance from the axis concerned.

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Q. 19. *Is there any other way of defining moment of Inertia ?*

Ans. Yes. There is another way. If I be the moment of Inertia and $\frac{d^2\theta}{dt^2}$ be the angular acceleration of the body, then the deflecting couple 'C' is given by $C = I \cdot \frac{d\theta}{dt^2}$ from which we get the definition.

"The moment of Inertia of a body about an axis is equal to the moment of the couple required to produce unit angular acceleration in the body about the axis of rotation".

Q. 20. *The moment of Inertia in rotational motion is the counterpart of mass in translational motion. Now since the mass 'm' is constant, so the moment of inertia 'I' should also be a constant quantity. Is it not so ? Give one example.*

Ans. No ; it is not the case. The moment of inertia of a body is dependent on the manner in which the mass is distributed about the axis of rotation.

For instance, the moment of inertia of a cylinder about its own axis is $\frac{1}{2}Mr^2$, while the moment of inertia of the same cylinder about an axis passing through its middle-point and perpendicular to its axis is $M\left[\frac{l^2}{12}+\frac{r^2}{4}\right]$.

Q. 21. *When will the moment of inertia of a body be minimum ?*

Ans. The moment of inertia of a body will have a minimum value when it rotates about an axis which passes through its centre of gravity and which is normal to the smallest cross-section of the body.

Q. 22. *What do you mean by the term, 'radius of gyration' ?*

Ans. It is defined as the distance from the given axis of rotation to the point where the mass of the body may be supposed to be concentrated so that it has the same moment of inertia as it possesses about the given axis.

For instance, if the moment of inertia of the body be expressed in the form MK^2 where M is the mass of the body, then K is known as the radius of gyration.

Q. 23. *What is the radius of gyration of the regular body (Disc) ?*

Ans. The disc is rotating about a normal axis passing through its centre. Under this circumstances, its moment of inertia is equal to $\frac{Mr^2}{2}$ so that the radius of gyration of this disc is $\frac{r}{\sqrt{2}}$.

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SECTION B

*EXPERIMENT 13

To study a Fortin's barometer and to measure the atmospheric pressure at a room temperature at a place.

Apparatus

(1) Fortin's barometer, (2) A thermometer, (3) Plumb line.

Theory :

(*i*) Pressure = $H_0\, dg$ dynes/cm^2

where H_0 = corrected barometric height

d = density of mercury = 13.6 g/cm^3

and g = acceleration due to gravity

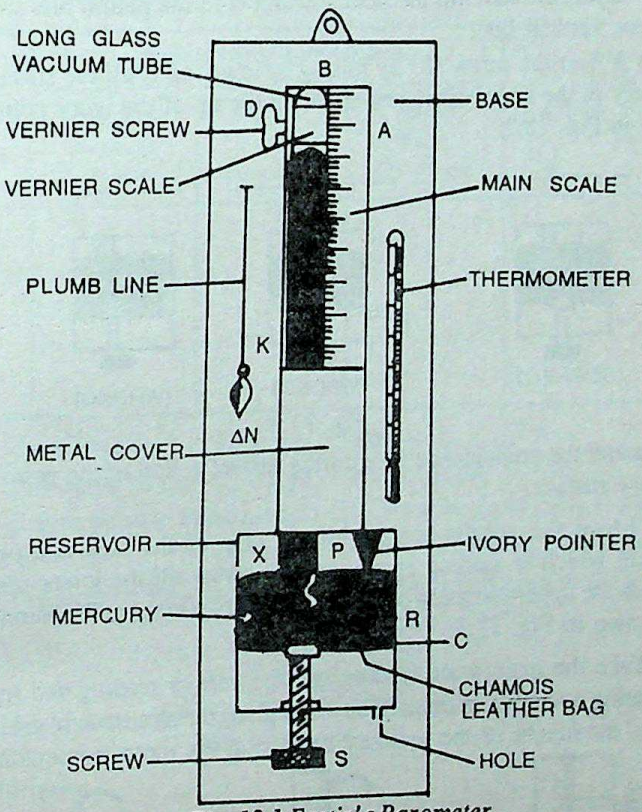

Fig. 13.1 Fortin's Barometer

(*ii*) $H_0 = H_t\,[1 - (\gamma r - \alpha)t]$

where H_t = Barometer reading at t°C.

* Not to be given as an experiment. It is included in the list of activities.

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H_0 = Barometer height *i.e.*, the height of mercury column giving the atmospheric pressure at 0°C.

α = Coefficient of linear expansion of the material of main scale.

γ_r = Coefficient of real cubical expansion of mercury

t = Room temperature

Now $\alpha = 0.000018$ for brass

$\gamma_r = 0.00018$ for mercury

$\therefore$ $H_0 = H_t [1 - 0.000162\ t]$

Procedure :

(*i*) Find the vernier constant of the vernier.

(*ii*) Adjust the base till the points K and N of the plumb line are just in the same vertical line.

(*iii*) Adjust the screw 'S' by raising or lowering it till the surface of the mercury in the reservoir is just touching the tip of the ivory pointer P as shown in Fig. 13.2.

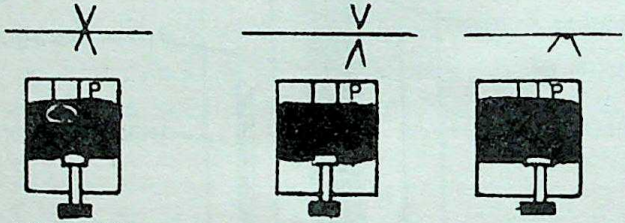

Fig. 13.2

Examine the coincidence by viewing the reflection of the point P at the mercury surface.

(*iv*) Move the vernier scale with the help of the rack and pinion arrangement which is worked by means of a screw till the lower edge is in level with the upper-most convex part of mercury surface in the barometer tube as shown in Fig. 13.3.

(*v*) Take the main scale reading and the vernier reading and repeat the observation a number of times. The mean gives the atmospheric pressure in terms of the height of the mercury column at the room temperature.

Fig. 13.3.

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(*vi*) Note the room temperature with the help of the thermometer fitted with the barometer tube. Apply the correction and find the value of H_0 *i.e.*, the barometer height at 0°C.

Observations and Calculations :

No. of divisions per cm on the Main Scale = m = ...

No. of divisions on the vernier scale = n = ...

$\therefore$ Vernier constant = $\frac{1}{m} \times \frac{1}{n}$ =..... cm

(*a*) **Atmospheric Pressure**

Room temperature (t) = ... °C

S.No.	Fortin's Barometer Reading			H_t = Height of Hg column at t°C = (1) + (2) in cm
	Main Scale Reading (1) cm	Vernier division coinciding	Vernier Value (2) in cm	
1.				
2.				
3.				
4.				

Mean Height H_t of Mercury column = ... cm

Now $H_0 = H_t [1 - 0{\cdot}000162\ t]$ = ... cm

$\therefore$ Atmospheric Pressure at 0°C = $P_0 = H_0\, dg$ = ... dynes/cm^2

Result :

Atmospheric Pressure = ... cm of Hg column at 0°C

= ..... dynes/cm^2 at 0°C

= ..... N/m^2

at ..... (Place of experiment)

on ..... (Date of experiment)

Precautions :

1. The barometer tube must be vertical.

2. The surface of the mercury in the bag should just touch the tip of the pointer in the bag.

3. The lower edge of the vernier scale should just appear to touch the uppermost portion of the mercury surface.

4. The eye must be at the same level as the vernier scale.

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Sources of Error

1. The space above mercury is not complete vacuum but contains vapours of mercury which exert a very small pressure.

2. Any change in the room temperature changes the density of mercury which in turn affects the observation.

Exercise

Q. 1. *To find the height of the water barometer in the laboratory ?*

Hint : Height of the water barometer = $H_0 \times 13{\cdot}6$ cm

ORAL QUESTIONS

Q. 1. *What is Atmospheric Pressure ?*

Ans. The air has its own weight and so exerts a pressure. The amount of this force per unit area exerted by the atmosphere is called the atmospheric Pressure. It is measured in terms of mercury column that this pressure can support. Normal atmospheric pressure is 76 cm of Hg.

Q. 2. *What is the unit of Pressure ?*

Ans. Its unit is dynes/cm^2 in C.G.S. system and newton/metre^2 in the S.I. system.

Q. 3. *Why is the atmospheric pressure expressed in terms of length ?*

Ans. As the pressure = hdg and as 'd' and 'g' are constant, therefore, pressure $\propto h$. The height is, therefore, taken as a convenient measure.

Q. 4. *Why do you use mercury in a barometer ? Can we use water ?*

Ans. We use mercury because it is the heaviest liquid and hence the length of the barometer is conveniently small, about 76 cm.

We can use water also but since mercury is 13·6 times heavier than water, the height of water barometer will be $76 \times 13{\cdot}6 = 10{\cdot}3$ m approximately which will be very cumbersome. Besides this, mercury exerts very small vapour pressure.

Q. 5. *Why should the surface of the mercury be adjusted to touch "Ivory Point" in a Fortin's barometer ?*

Ans. Ivory point represents the zero of the vertical main scale and the surface of mercury has to be adjusted to zero level to take the correct reading.

Q. 6. *Is the pressure the same in every direction ?*

Ans. Yes ; the pressure in different directions at the same level is the same.

Q. 7. *State Pascal's Law.*

Ans. Pressure applied anywhere on a confined liquid is transmitted equally in all directions.

Q. 8. *If the barometer tube were wider, will there be any change in the height of mercury column ?*

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Ans. No ; the shape of the tube has no effect upon the vertical height of the mercury column supported in the tube.

Q. 9. *If the Barometer tube were inclined, will there be any change in the height of mercury column ?*

Ans. It is the vertical height of mercury column which is a measure of atmospheric pressure. If the tube is inclined a little, the space above the free surface of mercury decreases, but its vertical height remains the same.

Q. 10. *Do you know any barometer which does not contain liquid ?*

Ans. Yes ; Aneroid Barometer—a more convenient and portable form of barometer whose reading is not affected by any change in position.

Q. 11. *Which barometer will you carry in an aeroplane to know its height and why ?*

Ans. Aneroid Barometer. The Aneroid barometer when used to find height attained by an aeroplane is known as *Altimeter*.

It is very compact and portable and is very sensitive to changes in atmospheric pressure.

Q. 12. *How do you forecast weather changes with a barometer ?*

Ans. (*i*) A falling barometer indicates the coming of rain and storm because the moist air is lighter than dry air, its density being 0·62 times as much as that of air.

(*ii*) A steady barometer indicates settled weather, and

(*iii*) A rising barometer indicates fair and dry weather.

Q. 13. *What do you understand by the statement that the atmosphere pressure is 76 cm of mercury ?*

Ans. It is the pressure exerted by a column of mercury 76 cm in height at 0°C at sea-level and at latitude 45°. This is known as the pressure of *one atmosphere* and is taken to be the standard for comparison.

The standard atmospheric pressure $= 76 \times 13{\cdot}6 \times 981$ dynes/cm^2

or The normal atmospheric pressure $= 1{\cdot}013 \times 10^6$ dynes/cm^2

$= 1{\cdot}013 \times 10^5$ N/m^2

Q. 14. *Does the atmospheric pressure change as one moves up in the atmosphere ? If so, in what manner ?*

Ans. As we go higher into the atmosphere, the pressure decreases. For some altitudes, the fall in the atmospheric pressure is about 0·25 cm for every 270 metres ascent. Thus a barometer, which reads 75 cm at sea level will read 74·75 cm at 270 m above sea level. After a few hundred metres, however, the fall in pressure is not regular.

Q. 15. *What will happen if a hole is drilled at the top of the barometer tube.*

Ans. Mercury column will not stay in the barometer tube.

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EXPERIMENT 14

To study the variation in volume of a sample of air with its pressure at constant temperature. Also use the study to find the atmospheric pressure.

OR

To verify Boyle's Law for a gas and use it to find the atmospheric pressure.

Apparatus :

Boyle's Law apparatus, Fortin's Barometer, Thermometer, plumb line and set squares.

Theory :

According to Boyle's Law, "Temperature remaining constant, the pressure of a given mass of a gas is inversely proportional to its volume".

$$P \propto \frac{1}{V}$$

or PV = constant (provided the temperature T is constant) ;

so if a graph is drawn between P and V, it will be found to be a *rectangular hyperbola* because PV = constant is the equation for it but the graph between P and $\frac{1}{V}$ will be a *straight line.*

But V = al where l is the length of the air column and 'a' is the area of cross-section of the tube.

$\therefore$ $P\ a\ .\ l$ = constant

As 'a' is constant ; therefore, Pl = constant.

or $P_1l_1 = P_2l_2 = P_3l_3 = \ldots\ldots$ = constant.

or $P \propto \frac{1}{l}$

$\therefore$ Graph between P and $\frac{1}{l}$ will be a straight line.

Procedure :

1. Find the vernier constant of Fortin's Barometer. With the help of the screw provided at the bottom end of the barometer, adjust the mercury level in the cistern till the mercury level touches the ivory head in the cistern. Hold eye in the front of the mercury level in the tube. Slide the vernier till zero of the vernier just touches the mercury level. Read the mercury level on the scale. It gives the atmospheric pressure (H).

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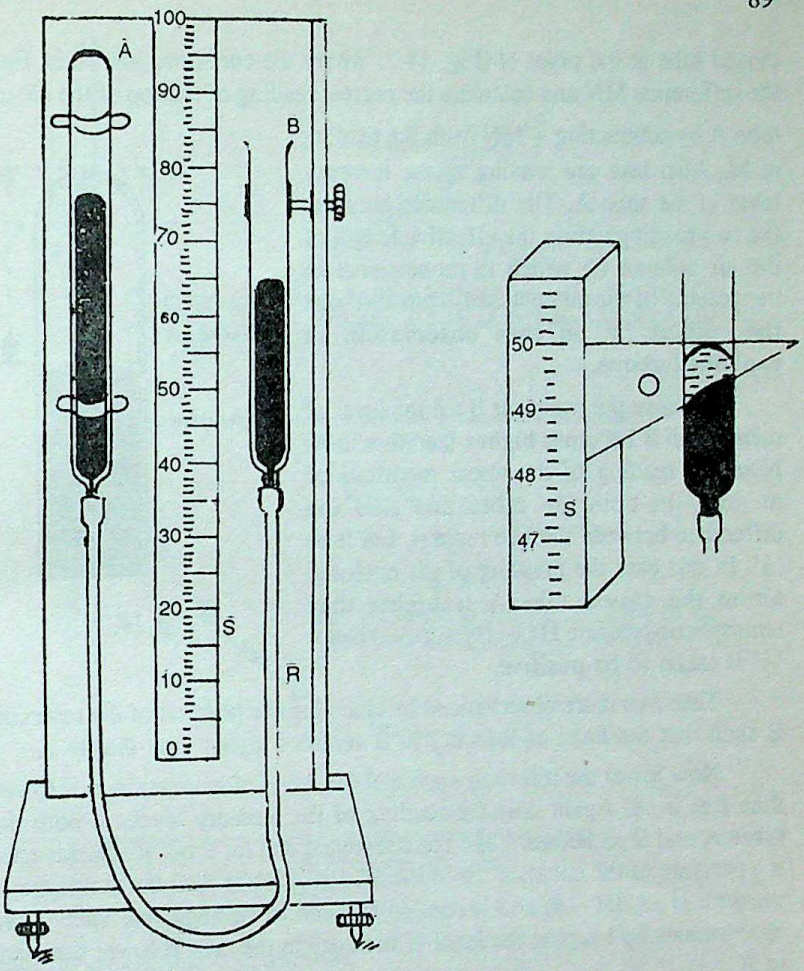

Fig. 14.1. Boyle's Law Apparatus

2. Note the room temperature by the thermometer provided by the barometer. If not provided, use another thermometer.

3. Set the Boyle's Law apparatus vertical with the help of a plumb line and levelling screws. Make sure that the reservoir B can be raised or lowered freely along the vertical board.

4. Slide the reservoir B along the vertical scale so that the mercury stands almost at the same level in both the tubes and it is nearly in the middle of the tube A.

5. Take the reading at the top end of the closed tube at M with the help of a set square setting one of its edges parallel to the vertical scale and the other tangential to the curved surface. Take another reading of the

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closed tube at the point N (Fig. 14.2) where the curvature just ends. Find the difference MN and calculate the correct reading of the top of the closed tube A by subtracting $\frac{1}{3}$ MN from the reading at M. Also take the reading of the mercury level in the tube A. The difference between the two readings gives the effective length of the air column (l) which is proportional to the volume of the air enclosed. Thus **find out the volume 'V' in each observation as explained above.**

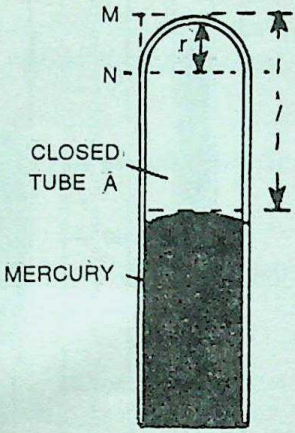

Fig. 14.2

6. Raise the reservoir B till the level of mercury in B becomes **higher** than that in A. Note the reading of the upper meniscus of mercury in both the tubes and find the difference between the two redings. Let it be 'h'. In this case the pressure of the enclosed air in the closed tube A is higher than atmospheric pressure H *i.e.*, (H + h) and hence 'h' is taken to be **positive.**

Take two more observations by changing the position of the reservoir B such that the level of mercury in B remains higher than that in A.

Now lower the reservoir such that the level of mercury in B is **lower** than that in A. Again note the reading of the mercury levels in both the tubes A and B as before. Take the difference and let it be 'h'. In this case the pressure of the enclosed air in the tube A is lower than the atmospheric pressure H *i.e.* (H – h) and hence 'h' is taken to be **negative.** Take **three** observations by keeping the level of mercury in the tube B lower than that in A.

Thus in all take atleast **six** observations.

7. Take the barometer reading again at the end of the experiment. Also note the room temperature at the end of the experiment.

8. Multiply the pressure P = (H ± h) of the gas with its respective volume 'V' and show that the product PV = constant in each case and hence the Boyle's Law is verified.

9. Plot a graph between P and V, taking P along X-axis and 'V' along Y-axis which will be a parabola (Fig. 14.4).

Find $\frac{1}{V}$ for different observations and draw a graph between P and $\frac{1}{V}$ which is a straight line (Fig. 14.5).

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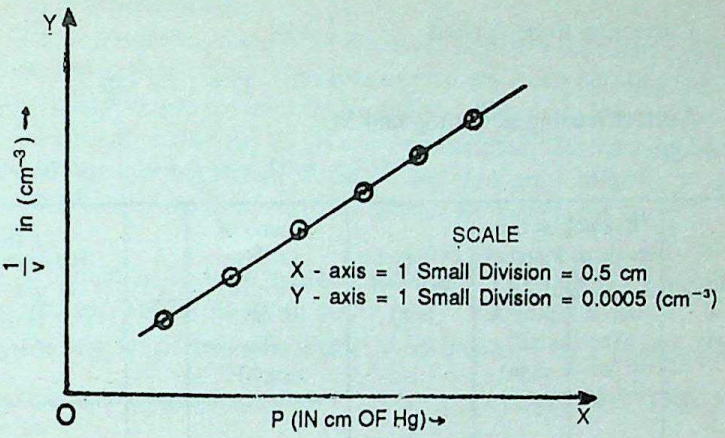

Fig. 14.3.

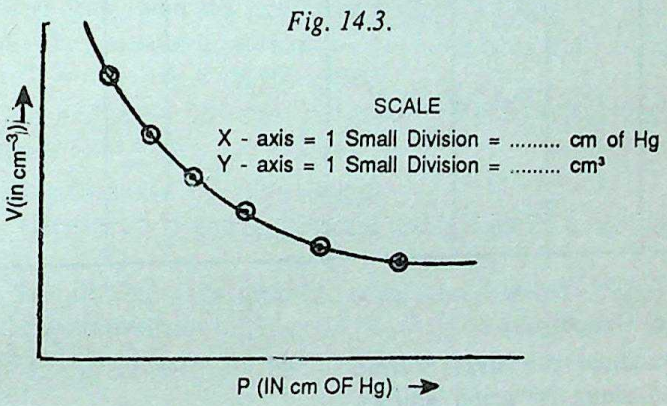

Fig. 14.4

Observations and Calculations

Room temperature at the beginning of the experiment = ... °C

Room temperature at the end of the experiment = ... °C

Barometer reading in the beginning = H_1 = ... cm of Hg

Barometer reading at the end = H_2 = ... cm of Hg

Mean barometric reading $= H = \frac{H_1 + H_2}{2}$

= ..... cm of Hg

Reading at the top end 'M' of the closed tube $= x$ = ... cm

Reading at the point 'N' where the curvature ends

$= y$ = ... cm

Difference = MN = $(x - y)$ = ...cm

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Correction to be applied $= -\frac{1}{3}$ MN

$= -\frac{1}{3}(x - y) =$ ..... cm

Correct reading at the top end M

$= x - \frac{1}{3}(x - y) = l =$ ..... cm

No. of obs.	Reading at the levels of mercury in		Difference I~II = h (cm)	Volume of air (V) = I – II in cm (V∝ effective length)	$\frac{I}{V}$	Pressure of gas P = H±h (cm of Hg)
	tube B (I) (cm)	tube A (II) (cm)				
1.						
2.						
3.						
4.						
5.						
6.						
7.						

Atmospheric Pressure :

(*a*) **Graphically :**

Produce the straight line obtained from the graph between difference 'h' in the mercury levels of the two tubes A and B (Fig. 14.1) and $\frac{1}{V}$ so as to meet the Y-axis at 'C' as in Fig. 14.5. Note the readings of the pressure OC at this point which is atmospheric pressure.

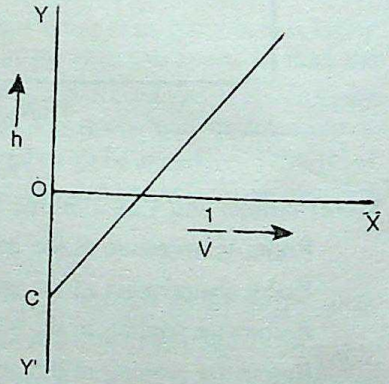

Fig. 14.5

Theory :

$$(H + h)\, V = K \text{ (constant)}$$

or $$H + h = \frac{K}{V}$$

But at C, $\frac{1}{V} = 0$, or $(H + h) = 0$

Or $H = -h$

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(*b*) **Mathematically :**

The atmospheric pressure 'H' can easily be determined from any two different observations. For differences of mercury levels 'h_1' and 'h_2' let the corresponding gas volumes be V_1 and V_2. Then from the relation

$(H \pm h_1) V_1 = (H \pm h_2) V_2$; H can be calculated. The most important precaution for this experiment is that V_1 and V_2 should differ by at least 3 cm. The smaller the difference, the greater the percentage error.

Result :

(*i*) Within the limits of experimental errors, the products PV are seen to be constant. This is Boyle's Law.

(*ii*) The graph between P and V is found to be a **rectangular hyperbola** and the graph between P and $\frac{1}{V}$ is a **straight line.** These two graphs also demonstrate the verification of Boyle's Law.

(*iii*) The atmospheric pressure on ..... (date) at ..... (time) and at ..... °C = ... cm of Hg (By graph)

= ..... cm of Hg (By calculation)

Precautions :

1. The apparatus should be vertical.
2. The mercury should be clean and should not stick to the sides of the tubes.
3. The position of the upper end of the tube A should remain fixed during the experiment.
4. Upper meniscus of the mercury should be read keeping the eye in level with it.
5. The mass of the gas in the tube A should not be changed during the experiment.
6. The reservoir should be raised or lowered very slowly and gently and wait before taking each reading.
7. Three readings should be taken for pressure greater than the atmospheric and three less than the atmospheric pressure.
8. Readings should be taken with the help of the set squares.
9. Readings of the atmospheric pressure and the room temperature should be taken before and after the experiment.
10. The correction for the curved part of the tube in the determination of the length of the air column should be applied.

Sources of Error :

1. The enclosed air may not be dry.
2. The room temperature and barometric height may change during the experiment.

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3. The mercury used is generally not as pure as in barometer and so there is a difference in their densities.

4. The closed end may not be uniform.

Exercise

To study the variations of volume of a sample of air with its pressure at constant temperature using a glass syringe with an improvised scale (e.g., a strip of graph paper).

ORAL QUESTIONS

Q. 1. *What is Boyle's Law ?*

Ans. Temperature remaining constant, the pressure of a certain mass of a gas is inversely proportional to its volume, *i.e.*,

$$P \propto \frac{1}{V} \text{ or } PV = \text{constant.}$$

Q. 2. *What are the limitations of Boyle's Law ?*

Ans. Actually gases show deviation from this law. Permanent gases, *e.g.*, air, N_2, O_2, H_2, etc., obey it fairly well under ordinary pressure and temperature.

It does not hold good at very high pressure and at very low temperature. It is not true for saturated vapours.

Q. 3. *What is a perfect (or ideal) gas ? Name some of them.*

Ans. A perfect gas is that which obeys Boyle's Law and Charle's Law. In fact no gas is perfect but permanent gases like O_2, H_2, N_2, etc., are very nearly so.

Q. 4. *What is the difference between gas and vapour ?*

Ans. A substance below its critical temperature is called a vapour, whereas a substance above its critical temperature is called a gas.

Vapour can be liquified by increasing pressure alone, while a gas cannot be liquified and has to be cooled below the critical temperature before it can be liquified.

Q. 5. *How do you keep the temperature constant ?*

Ans. By waiting for a short time after every observation so that the heat developed during compression may dissipate out.

Q. 6. *Should the change be isothermal or adiabatic in Boyle's Law ?*

Ans. Isothermal.

Q. 7. *How do you explain the fact that a small amount of gas in the tube sometimes exerts a greater pressure than even the whole column of the atmosphere ?*

Ans. During compression, the bombardment of the molecules of the enclosed gas against the sides of the tube increases and hence the pressure ;

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as the pressure is proportional to this bombardment and not to the mass of the gas.

Q. 8. *What is the difference between the following relations :*
(a) PV = constant and (b) PV = RT.

Ans. The first relation is Boyle's Law and the second relation is the gas equation obtained by combination of Boyle's Law and Charle's Law.

Q. 9. *What is the use of drying the gas ?*

Ans. Boyle's Law does not hold good accurately for moist gases. Application of pressure will condense some of the water vapour into water and hence the gas should be dry.

Q. 10. *Which graph will you prefer and why ?*

(a) P and V, (b) P and $\frac{1}{V}$, *(c) V and* $\frac{1}{P}$.

Ans. P and $\frac{1}{V}$ or V and $\frac{1}{P}$ graphs, as these are straight lines and errors are easily accounted for.

Q. 11. *Has the diameter of either the gas tube or the reservoir anything to do with the pressure to which the gas is subjected ?*

Ans. There will be no effect in either case, simply the quantity of mercury required will be larger in the case of a wider tube.

Q. 12. *If in the Boyle's Law apparatus, the tube A is not graduated in c.c., how will you measure the volume in terms of length of the tube A above the level of mercury in it ?*

Ans. The upper part of the tube A (Fig. 14.2) is curved and as a result of it, a correction has to be applied for it. This is calculated as follows :

Volume of the curved portion

= Volume of the hemisphere of radius 'r'.

$$= \frac{1}{2} \times \frac{4}{3} \pi r^3 = \frac{2}{3} \pi r^3$$

If the curved portion had been flat, it would have formed a cylinder of length 'r' and also of radius 'r'. Then the volume of this cylinder

$$= \pi r^2 \times r = \pi r^3$$

$$\therefore \quad \text{Error in volume} = \pi r^3 - \frac{2}{3} \pi r^3 = \frac{1}{3} \pi r^3$$

$$\therefore \text{ The resulting error in length} = \frac{\text{Volume}}{\text{area}} = \frac{1}{3} \frac{\pi r^3}{\pi r^2} = \frac{1}{3} r$$

Correction in length $= \frac{1}{3} r = -\frac{1}{3}$ MN

Thus in order to obtain correct length (or volume as volume $\propto$ effective length), $\frac{1}{3} r$ should be subtracted from the observed length.

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EXPERIMENT 15

To measure surface tension of water by capillary rise method.

Apparatus :

Capillary tubes of uniform bore and different diameters (ranging from 0·5 to 1·5 mm) ; a glass strip, a thin rubber tube band, a needle, a glass vessel, a clamp stand, a travelling microscope ; a thermometer and an adjustable stand.

Theory :

When a capillary tube open at both ends is dipped vertically in a liquid, the surface of the liquid inside the tube is generally *curved*. If the liquid wets the tube as in the case of water, the surface is **concave upwards** and the pressure in the liquid just below the meniscus is less than the

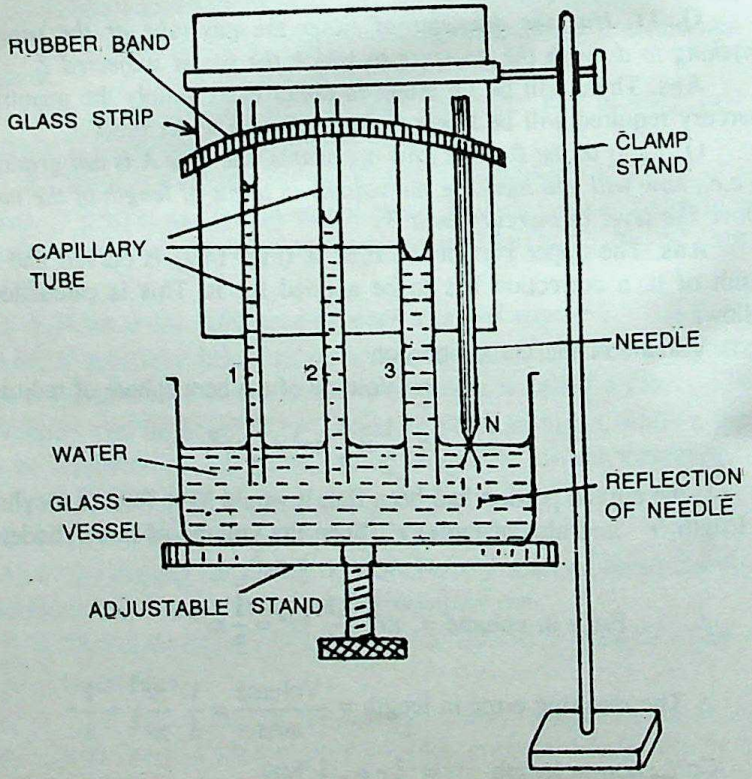

Fig. 15.1. Surface tension of water.

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atmospheric pressure above it by an amount $\frac{2T}{r}$ where T is the surface of tension of the liquid and 'r' is the radius of the tube, which is the same as the radius of curvature of the meniscus. Hence the liquid rises in the tube and the weight of the liquid in it balances the difference of pressure.

Let the height of the liquid in the tube from the horizontal surface in the vessel to the tangent plane CD at the bottom of the meniscus be 'h' and 'ρ' the density of the liquid. (Fig. 15.2).

$$\therefore \text{ Weight of the liquid column } = \pi r^2 \left[h + \frac{r}{3}\right] \rho g$$

The surface tension acts along the tangent plane to the liquid surface inwards and its reaction acts outward along AE or BF all along the meniscus which touches the inner surface of the tube all round the circumference $2\pi r$. The vertically upward components of this force support the weight of the liquid column.

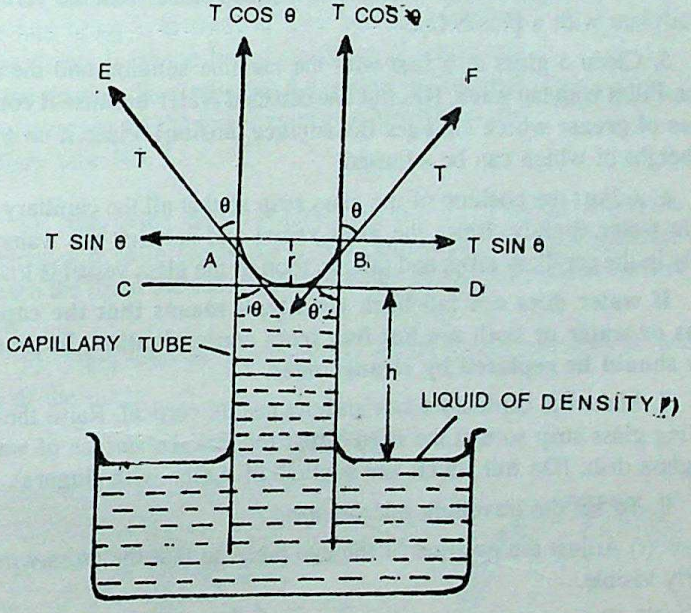

Fig. 15.2

$$\therefore \quad 2\pi r \, T \cos\theta = \pi r^2 \left[h + \frac{r}{3}\right] \rho g$$

$$\text{or} \quad T = r \frac{\left[h + \frac{r}{3}\right] \rho g}{2 \cos\theta}$$

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For liquids which wet* glass, the angle of contact $\theta = 0$

$$\therefore \quad T = r \frac{\left[h + \frac{r}{3}\right] \rho g}{2}$$

Procedure :

1. Select three capillary tubes of different diameters (ranging from 0·5 to 1·5 mm) and cut off their sealed ends with a sharp file or a blade.

2. Clean the capillary tubes carefully first with caustic soda and then with nitric acid, washing out the nitric acid with considerable quantities of water. Then dry the tubes with dry air forced through them.

3. Mount the capillary tubes on a glass strip with a rubber band, such that the distance between them is about one cm. Also mount a thin needle on the glass strip parallel to capillary tubes (Fig. 15.1) so that its fine end projects a little less than that of the capillary tubes.

4. Hold the glass strip vertically in a clamp stand. Test the verticality of the plate with a plumb line.

5. Clean a glass dish first with the alkaline solution and then with water. Fill it with tap water. **(Do not use distilled water because it contains traces of grease which changes the surface tension).** Place it on a stand the height of which can be adjusted.

6. Adjust the position of the glass strip so that all the capillary tubes dip in water slightly. Raise the glass vessel and see that the water rises freely in the capillary tubes and falls as soon as the glass vessel is lowered.

If water does not fall back readily, it means that the capillary tubes or water or both are not free from contamination. In that case they should be replaced by cleaner ones.

7. Make the capillary tubes and the needle vertical. Raise the stand holding glass strip so that the needle just touches the surface of water in the glass dish. **(Do not touch the surface of water with fingers).**

8. To set the travelling microscope :

(*i*) Adjust the position of the eye piece so that the cross-wires are clearly visible.

(*ii*) Place the microscope with its horizontal traverse parallel to the plane of the glass plate.

(*iii*) Adjust one of the levelling screws at the base of the microscope so that its scale is vertical and the microscope tube is horizontal. Test with a spirit level.

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*This will be so when the bore of the capillary tube is very fine. Thus this assumption is only partially true in actual practice.

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9. Direct the microscope on the capillary tube having the maximum height of water in it. Focus it by removing parallax between the cross-wires and the image of water column in the capillary tube. Lower the microscope vertically and make sure that it can reach the water level. Rotate the eye-piece of the microscope to make one of the cross-wires horizontal.

Adjust the position of the microscope so that the horizontal cross-wire is approximately at the position M (Fig. 15.3) of the meniscus of water in capillary tube No. 1 having the greatest rise of water.

Work the screw at the top of the microscope till the cross wire is exactly in the position M. Read the vertical scale.

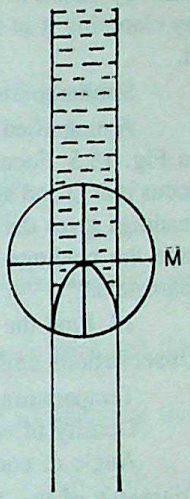

Fig. 15.3. Magnified view of capillary tube No. 1

10. Move the microscope along the horizontal scale and bring it in front of tube No. 2. Adjust its height, focus it on the lower meniscus of water and note the reading. Similarly take the reading by focusing the microscope on the lower meniscus of water in the capillary tube No. 3.

11. Now bring the microscope in front of the needle and lower it till the cross-wire is in the position N as shown in Fig. 15.4 symmetrically between the tip of the needle and its image in water. Read the vertical scale again.

12. Mark with pen the position of the lower meniscus of water in each of the tubes.

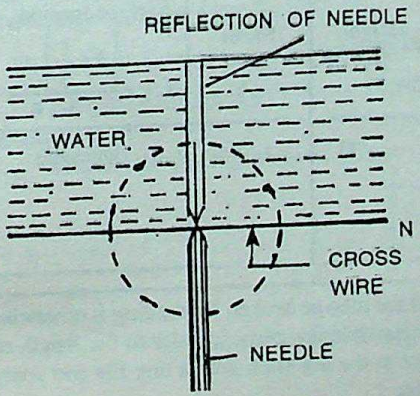

Fig. 15.4.

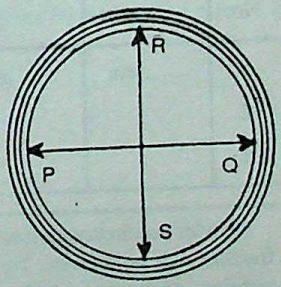

Fig. 15.5

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13. Measurement of the diameter : *Cut the tube No. 1, at the ink mark by means of a sharp glass cutting file and find its internal diameter by clamping it in a horizontal position and focusing the microscope over it.

Similarly find the diameters of the capillary tube Nos. 2 and 3.

A magnified view of the cross-section of the capillary tube is shown in Fig. 15.5. Focus the microscope first at P and note the reading. Now focus it at Q and again note the reading. The difference between these two readings gives the diameter PQ. Rotate the tube through a right angle and take the readings at R and S. Find the mean of the values of the two diameters.**

14. Find the temperature of water used.

Observations and Calculations :

Temperature of water = t = ... °C

Density of water at t°C = ... g/cm^3

Angle of contact for water = θ = ...(from tables)

Diameter of the Tube :

Vernier constant of the microscope = ... cm

Capillary tube No.	Microscope reading at				PQ	RS	Mean diameter	Mean radius (r)
	P	Q	R	S				
1.	...cm	...cm	...cm	...cm	...cm	...cm	...cm	...cm
2.								
3.								

Height of the liquid column and surface tension :

Capillary tube No.	Reading at		Height (h)	Mean radius (r)	Surface tension $T = r\dfrac{\left[h+\frac{r}{3}\right]\rho g}{2\cos\theta}$
	M	N			
1.	..... cm	.....cm	.....cm	.....cm	..... dynes/cm
2.					
3.					

*Under no circumstances should the tube be broken by bending it otherwise the fracture will be uneven. To get a clear fracture perpendicular to the length of the capillary, make a scratch on the tube at the ink mark with a tiny file and apply the tension *along* the length of the tube.

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** The four readings should vary (if at all) amongst themselves by a very small amount.

Mean value of Surface Tension = ... dynes/cm

Value from tables at room temperature = ... dynes/cm

% error = ...

Result :

The surface Tension of water at ..... °C= ..... dynes/cm

Precaution :

1. The tubes should be of uniform bore throughout.
2. The tubes must be vertical and sufficiently apart.
3. Water should rise freely in the tubes.
4. Do not use wax for fixing the tubes on the glass plate. Instead use a thin rubber band.
5. The surface of water should not be touched with hand and the vessel containing it should not be greasy.
6. The diameters of the tubes should be measured accurately at the points where the liquid level stands.
7. The diameter should be measured accurately in two mutually perpendicular directions.
8. The tip of the needle should just touch the water surface and not dip into it.
9. The back-lash error with the microscope should be avoided by always turning the screw in the same direction.

Sources of Error :

(*i*) Probable contamination of the liquid surface as also the contamination of the capillary tube ; the cleaning of which is tedious.

(*ii*) Chief source of error is the determination of the radius of the bore as it is extremely difficult in practice to have a capillary tube of absolutely uniform bore throughout.

Exercise

Compare the radii of the two capillary tubes by noting the rise of the liquid in them.

Hints : If the liquid wets glass

$$T = \frac{r\left[h + \frac{r}{3}\right]\rho g}{2}$$

If the radius (r) is small then $\frac{r}{3} << h$

$$\therefore \quad T = \frac{r\,h\,\rho g}{2}$$

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If h and h' are the heights of liquid columns in the two capillary tubes of radii r and r' respectively, then

$$2T = rh\rho g = r' h' \rho g$$

or

$$\boxed{\frac{r}{r'} = \frac{h}{h'}}$$

ORAL QUESTIONS

Q. 1. *What do you mean by surface tension ?*

Ans. The free surface of every liquid behaves as if it were in a state of tension having a natural tendency to contract. This tension or pull in the surface of a liquid is called *Surface Tension.* If a line be imagined to be drawn on a liquid surface, a force acts on each side of this line, the direction of the force being tangential to the surface and perpendicular to the line. *The magnitude of this force acting per unit length of this line is known surface tension.*

Q. 2. *Is there any other way of defining surface tension ?*

Ans. Yes. The surface tension may also be defined as numerically equal to the work done in enlarging the surface of a liquid by unit amount under isothermal conditions.

Q. 3. *Why should work be at all done in enlarging the surface of a liquid ?*

Ans. As the surface is enlarged, the surface density of the molecules, *i.e.*, the population of the molecules per cm^2 of the free surface, is diminished. Consequently more molecules must be brought to the surface from the interior of the liquid in order to keep this population constant. To give room to these new-comers on the surface, the adjacent molecules have to be separated. Thus work is necessary to separate the molecules against the cohesive forces which are existent between the molecules.

Q. 4. *What happens to the energy which constitutes the work done ? Is it wasted ?*

Ans. No. This energy is not wasted, but is stored in the surface molecules in the form of enhanced potential energy. It is due to this fact that the surface of a liquid behaves like a stretched membrane.

Q. 5. *Why mercury does not stick to the finger, while water does under the same conditions ?*

Ans. In the case of mercury the force of cohesion between mercury and mercury is *greater* than the force of adhesion between mercury and finger. Hence the molecules of mercury just in the neighbourhood of the finger are unable to be torn off from the parent mass of the liquid. Consequently mercury does not stick to the finger.

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In the case of water, however, *the adhesive forces are stronger than the cohesive forces*; hence when the finger is dipping in water, the molecules of water close to the finger leave the liquid and stick to the finger. Consequently the finger gets wetted.

Q. 6. *What is the nature of these cohesive forces ?*

Ans. These forces are not of the same nature as gravitational forces but arise on account of the interaction of the electrical fields which surround atoms. **These are very short-range forces.** Their influence is experienced in a very narrow range of order of 10^{-5} mm. Thus, if two molecules be separated by a distance greater than this, the cohesive force existent between them becomes insignificantly small.

Q. 7. *Why water rises in a capillary tube ?*

Ans. In the capillary tube (Fig. 15·6), the water meniscus is concave. Now, as the surface of a liquid behaves like a stretched membrance and wants to contract as much as possible, the surface in the tube becomes straight as shown by the dotted line. Hence space below this dotted line is filled by water.

Now, the meniscus cannot remain straight, it again becomes concave. Due to surface tension it again becomes straight. This process of straightening and curving of the meniscus continues and consequently water rises in the tube.

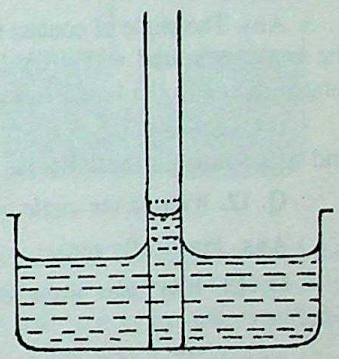

Fig. 15.6. Why water rises ?

Q. 8. *Should the water level continue to rise indefinitely ?*

Ans. No. Each time when the surface straightens and water rises, the surface has to pull a column of water. Now, when the weight of the water column becomes so great that the tendency of the surface to straighten up is checked, the water level ceases to rise. Hence the rise of water column is not indefinite.

Q. 9. *Why does water not rise in an ordinary glass tube—, why in a capillary tube ?*

Ans. The height of water column in a glass tube depends upon the weight of the liquid contained in this column. This obviously depends upon the radius of the tube. In a capillary tube the radius is exceedingly small, hence the weight of the liquid for balancing surface tension is attained in a good length of the tube. In a wide tube or ordinary glass tube, the same weight of water will be contained in an extremely small length of the tube and the rise may not even be perceptible.

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Q. 10. *What is the relation between surface tension and weight of the liquid column supported by it ?*

Ans. $2\pi r\ T \cos\theta = \pi r^2 g\left[h + \frac{r}{3}\right]\rho$

[See Theory of the Expt. above]

Q. 11. *Define angle of contact.*

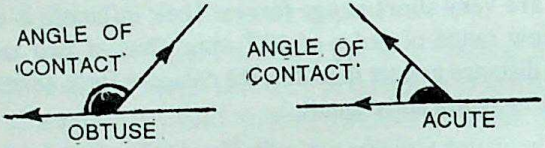

Fig. 15.7.

Ans. The angle of contact (Fig. 15.7) between a liquid and a solid is the angle measured within the liquid, between the solid surface and the tangent plane to the liquid surface at the point of intersection.

It is **obtuse** in the case of liquids which do not wet the solid surface and it is **acute** for those liquids which wet the solid surface.

Q. 12. *What is the angle of contact for pure water-glass interface ?*

Ans. Practically *zero.*

Q. 13. *Why does water assume concave meniscus in a capillary tube?*

Ans. In Fig. 15.8 consider a molecule 'M' of water. Let force of adhesion (F_1) between the water molecule M and glass molecules and the force of cohesion (F_2) between the water molecule (M) and the rest of the water molecules be represented in magnitude and direction by $\overrightarrow{MA}$ and $\overrightarrow{MB}$ respectively. In this case of water-glass interface, $F_1 > F_2$ consequently the resultant R represented by the diagonal $\overrightarrow{MQ}$ takes the direction as shown. This is a force experienced by the surface just in the vicinity of this molecule M. Now, for equilibrium, the surface of the liquid must be at right angles to the resultant force acting on it. This can be achieved by the **surface curving upwards** as shown. Now if we consider the other wall of the capillary tube, it is clear that inside it the surface must curve upwards for both the walls. Hence the surface must be concave.

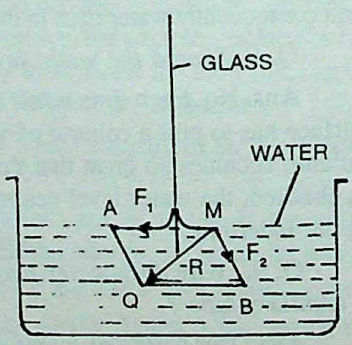

Fig. 15.8. Concave meniscus.

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Q. 14. *Do all liquids show this behaviour, i.e., assume concave meniscus in a capillary tube ?*

Ans. No. The case discussed in (Q. 13) is true only for those liquids and those surfaces, in contact with them, for which **force of adhesion is greater than the force of cohesion.** For those liquids, for which reverse is the case, the surface is **convex.** For example mercury and glass surface.

Q. 15. *If a capillary tube is dipped in mercury, what will you observe ?*

Ans. The level of mercury in the capillary tube will go on sinking.

Q. 16. *When will it stop sinking ?*

Ans. When the tendency of the meniscus to contract downwards is counterbalanced by the hydrostatic pressure exerted by the mercury column due to difference '*h*' (Fig. 15.9) between the levels of mercury in the outside vessel and inside the capillary tube.

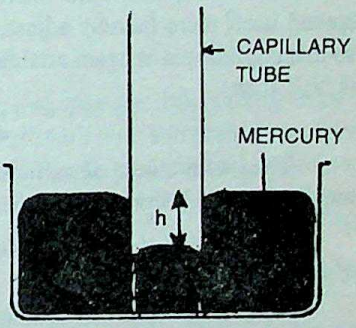

Fig. 15.9.

Q. 17. *Can we use a tube in this experiment whose bore may not be uniform throughout ?*

Ans. Of course we can use a capillary tube of this type provided the radius is measured at the place where the meniscus is formed. Theoretically there is no difficulty but practically, there will be one probable source of error.

Q. 18. *What will be that probable source of error ?*

Ans. If the tube is cut even slightly up or down the desired point for the determination of the radius of the tube, there will be serious error in the value of '*r*', the radius of the tube. Hence the result will be off the mark.

Q. 19. *Suppose we dip a number of tubes of the same bore but made of different materials, in the same liquid, will we get the same rise in all ?*

Ans. No ; because the interfacial surface tension will be different in each case.

Q. 20. *Suppose there are two tubes A and B. The bore of A is circular, that of B is elliptical—the major axis of the ellipse is equal to the diameter of the former. How will the levels in the tubes be affected ?*

Ans. The rise in the elliptical tube will be *more* than in the circular one.

Q. 21. *Suppose the liquid occupies 5 cm of the tube when it is held vertically in the liquid. Now, if the tube is inclined at an angle of 60° to the vertical, how will the rise in tube be affected ?*

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Ans. The length of the liquid column occupying the tube shall increase in such a way that the vertical height is even now 'h'. So the angle of inclination is 60°, we have

$l \cos 60° = h$ or $\boxed{l = 10 \text{ cm}}$ where l is the length of the liquid in the tube in the inclined position.

Q. 22. *Suppose the expected rise in a capillary tube is 10 cm ; but we have a tube only 8 cm long. When dipped, will water overflow ?*

Ans. No. When water shall reach the top of the tube, it will slightly spread itself there thereby adjusting its radius of curvature to a new value so that equilibrium is again established. Suppose the new radius of curvature is 'r_1', then

$$r_1 \times 8 = r \times 10$$

Thus with a tube of sufficient length, r_1 will be greater than r or the meniscus shall become less concave.

Q. 23. *What is the unit of surface tension ? What are the dimensions of surface tension ?*

Ans. Unit → newton per metre (N/m)\

Dimensions : M^1T^{-2}

Q. 24. *How does surface tension vary with temperature ?*

Ans. The surface tension of all liquids *decreases* as the temperature rises.

Q. 25. *What is the effect of contamination on the surface tension of a liquid ?*

Ans. All sorts of impurities, contaminations and dissolved substances *lower* the surface tension of the liquid.

Q. 26. *Why raindrops are spherical in shape and bigger drops are left ?*

Ans. Because in the case of raindrops the surface tension is greater than the force of gravity and in the case of bigger drops, the weight of the drop is greater than the upward force of surface tension.

Q. 27. *What are the factors that affect surface tension of a liquid ?*

Ans. (*i*) Temperature, (*ii*) Contaminations ; impurities and dissolved substances.

□□

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EXPERIMENT 16

To determine the surface tension of a liquid (water) by the drop-weight method.

Apparatus :

Funnel, a short glass tube of internal diameter 4 mm or 5 mm, a piece of rubber tubing which can fit tightly on the glass tube, paraffin wax, small beaker or crucible, screw type pinch cock, travelling microscope, the given liquid (say water).

Theory :

Let us make a simplifying assumption that the drop falling from a circular orifice has cylindrical form when it is about to break away from the tube. If r is the radius of the orifice, the excess pressure inside the drop at this section is $\frac{T}{r}$ due to cylindrical curvature where T is the surface tension of the liquid. This produces a downward thrust on the drop of $\frac{T}{r} \cdot \pi r^2 = T\pi r$. If m is the mass of the drop, the total downward forces are $T\pi r + mg$.

These forces are balanced by the upward forces of surface tension round the circle of contact. This force is $2\pi r \cdot T$.

Hence $$2\pi r \cdot T = T\pi r + mg$$

or $$T = \frac{mg}{\pi r}$$

The above expression is deduced on the assumption that (*i*) the drops break away under ideal statistical conditions, and (*ii*) shape of liquid at the orifice is cylindrical when the drop is about to break away. The problem, however, is complicated by dynamical considerations and complex shape of drops. Taking these into account Rayleigh has shown that a closer approximation is given by the formula

$$\boxed{T = \frac{mg}{3 \cdot 8\, r}}$$

Procedure :

1. Place the funnel in a ring as shown in Fig. 16.1. Fix the glass tube to the lower end of the funnel with a rubber tubing. Attach the pinch cock on the rubber tube, to regulate the liquid flow. Make a thin coating of wax

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on the dropping end of the glass tube. This ensures that the drops fall out from its internal surface only. For this purpose, it is also necessary that the glass tube is cut flat. If the flat end is not obtained by cutting only, it may be grounded flat using a very fine emery powder or sand. In no case should it be fire polished.

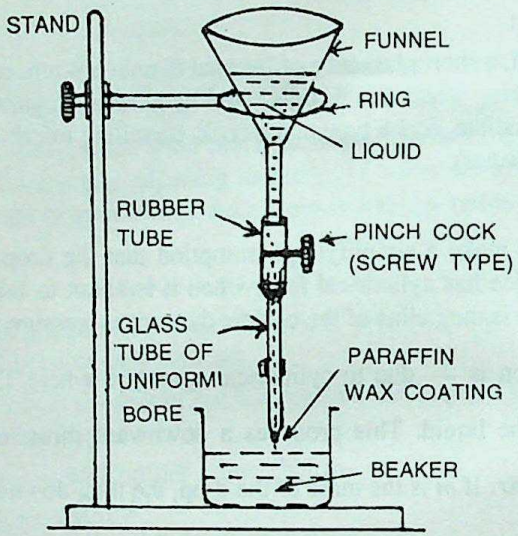

Fig. 16.1

2. Place the liquid whose surface tension is to be measured in the funnel. Regulate the flow of the liquid so that the drops break away at the rate of about one per minute. Collect the counted number of drops in a beaker of known mass and weigh the beaker with the collected liquid. From this, the average mass of the drop is found out.

3. The mean radius, r, of the end of the glass tube is determined by means of a travelling microscope as explained in Expt. 15.

4. Calculate the surface tension, T, using the formula

$$T = \frac{mg}{3 \cdot 8\, r}$$

where m is the average mass of a drop and g is the acceleration due to gravity.

Note. For more accurate measurement, the rate of breaking away of the drops should be even slower than what has been suggested above. It is better to keep it one drop every four minutes but it may take the experiment too much time consuming. When time is important, students may do a tolerable experiment even by collecting 50 drops in about 10 minutes.

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Observations and Calculations :

Mass of beaker = ... g

Mass of beaker and collected liquid = ... g

Number of drops = ...

Average mass of a drop (m) = ... g = ... kg

Diameter of the tube :

Vernier constant of the microscope = ... cm

Microscope reading at (in cm)				PQ (cm)	RS (cm)	Mean diameter (cm)	Mean radius (cm)
P	Q	R	S				
							..... (cm) ..... (cm)

$\therefore$ Mean radius of dropping end of glass tube = r = ... m

Acceleration due to gravity at ..... (from tables) = g = ... ms^{-2}

$\therefore$ Surface tension of the liquid

$$= T = \frac{mg}{3 \cdot 8\, r} = \text{.....} \text{ N/m}$$

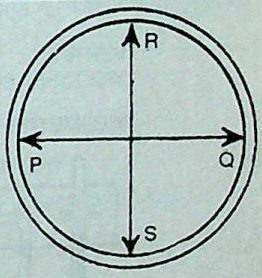

Fig. 16.2

Result :

The surface tension of the liquid = ... Nm^{-1}

Precautions :

1. The glass tube should be cut flat.
2. The drops of the liquid should fall out from the internal surface of the glass tube only.
3. The flow of liquid should be regulated in such a way that the drops break away at the rate of about one per 4 minutes or one per minute if time is important.
4. The glass tube should be of **uniform** bore throughout.
5. The diameter of the flat end of the glass should be measured accurately in two mutually perpendicular directions.

ORAL QUESTIONS

[Same as in Experiment 15].

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EXPERIMENT 17

To find the pressure of a sample of air at constant volume at different temperatures and to study the relationship between pressure and temperature of the sample of air at constant volume and hence determine the coefficient of increase of pressure of air at constant volume by Jolly's constant volume air thermometer.

Apparatus :

Jolly's constant volume air thermometer, a plumb line, a beaker, a thermometer, ice, a funnel, a set square, and a heating arrangement.

Theory :

A simple form of constant volume air thermometer (Fig. 17.1) due to Jolly consists of a glass bulb C at the end of a capillary tube about 1 mm

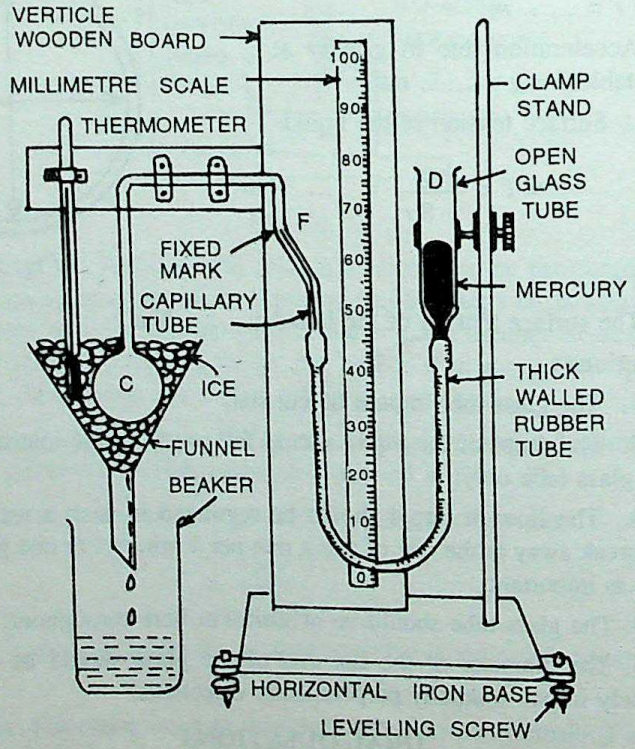

Fig. 17.1. Jolly's constant volume air thermometer.

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in diameter. The tube is bent twice at right angles and joined by a thick-walled rubber tubing to an open glass tube D. The part of the capillary tube attached to the bulb beyond the second bend is fixed vertically on a vertical wooden board fixed on a horizontal iron base provided with three levelling screws. A millimetre scale is fixed on the vertical board with its zero mark in the lower most position. The open tube which is also in front of the scale can slide up or down along the vertical board and can be clamped at any position. The rubber tube and the open tube contain mercury and during the experiment the level of mercury is kept at the fixed mark F on the capillary tube.

Gases expand much more than solids and liquids do. If a gas is heated but its volume is kept constant, the pressure of the gas will increase.

The coefficient of increase of pressure at constant volume is defined as the increase in pressure per unit pressure at 0°C, per degree centigrade rise of temperature, volume remaining constant.

If P_0 is the pressure at 0°C and P_t the pressure at t°C, then the coefficient of increase of pressure at constant volume γ_v is given by

$$\gamma_v = \frac{P_t - P_0}{P_0 \times t}$$

or

$$P_t = P_0 (1 + \gamma_v t)$$

The value of coefficient of increase of pressure at constant volume for all gases is $\frac{1}{273}$ or 0·00367.

In the case of gases the lower temperature must be 0°C and not the room temperature as an appreciable error will be caused due to the very large value of the coefficient of expansion of a gas *i.e.*, $\frac{1}{273}$ or 0·000367, which is approximately 10 times the coefficient of cubical expansion of water and 100 times the coefficient of cubical expansion of copper.

It is possible to determine the coefficient of expansion of a gas from readings of pressure at any two temperatures. If P_0, P_1 and P_2 are the pressures at temperatures 0°C, t_1°C and t_2°C respectively and γ_v is the coefficient of increase of pressure at constant volume, then

$$P_1 = P_0 (1 + \gamma_v t_1) \quad \ldots(i)$$

$$P_2 = P_0 (1 + \gamma_v t_2) \quad \ldots(ii)$$

Dividing (*ii*) by (*i*), we have

$$\frac{P_2}{P_1} = \frac{1 + \gamma_v t_2}{1 + \gamma_v t_1}$$

or

$$\gamma_v = \frac{P_2 - P_1}{P_1 t_2 - P_2 t_1} \quad \ldots(iii)$$

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Procedure :

1. Set the apparatus vertical as follows :

Suspend a plumb line in front of the scale. Adjust the levelling screws at the base so that the plumb line is parallel to the edge of the scale and equidistant from it at all points. **Adjust the central screw to make it parallel to the edge and the two side screws to make it equidistant.**

2. Make a fixed mark, F below the bend on the capillary tube by pasting a piece of gumpaper on it. **The mark is made below the bend so that mercury may not enter the bulb C due to negligence.**

3. Note the atmospheric pressure from Fortin's barometer as follows :

(*i*) Find the vernier constant of the Fortin's barometer.

(*ii*) Adjust the screw at the base of the barometer so that the mercury surface just touches the ivory tip.

(*iii*) Place the eye at the same level as the meniscus of mercury to avoid parallax and note the reading.

4. Bring the open tube D to the lowest position. Place a glass funnel below the bulb C. Wash ice in running water and pound it in a **clean duster.** Surround the bulb **completely** with pounded ice and suspend from a clamp a thermometer with its bulb dipping in ice near the glass bulb. Wait for about 10 minutes so that the air in the bulb attains the temperature of ice. Raise the tube D till the mercury level in the capillary stands at the fixed mark F.

5. Wait for a few minutes. If the air in the bulb has attained the temperature of ice and there is no leakage in the apparatus, then the mercury level will remain stationary at F.

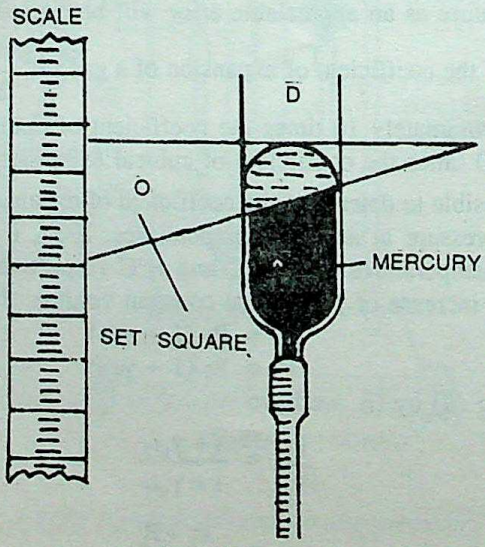

Fig. 17.2

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In order to note the reading of the upper meniscus of mercury in the open tube D, place a set square such that one of its perpendicular sides is horizontal and the other presses against the side of the metrescale as shown in Fig. 17.2. Move it till the horizontal edge is at the level of mercury. Place the eye at the same height **inorder to avoid error due to parallax** and note the scale reading against the horizontal edge of the set square. Similarly, note the reading of the mercury level on the scale against the fixed mark F.

6. Remove ice and the funnel surrounding the bulb C. Place the bulb in the steam bath as shown in Fig. 17.3. When the bulb remains surrounded with steam for about 10 minutes, the air in the bulb will attain the temperature of steam. See that the thermometer records a constant temperature. Raise the tube D so that mercury in the capillary tube again stands at the fixed mark F. Wait for a few minutes more. If the air in the bulb has attained the temperature of steam, the mercury level will remain stationary at F. Note the scale reading against the level of mercury in the tube D, with the help of a set square as explained in step 5 of the procedure. **Bring the tube D to its lowest position and then remove the burner.**

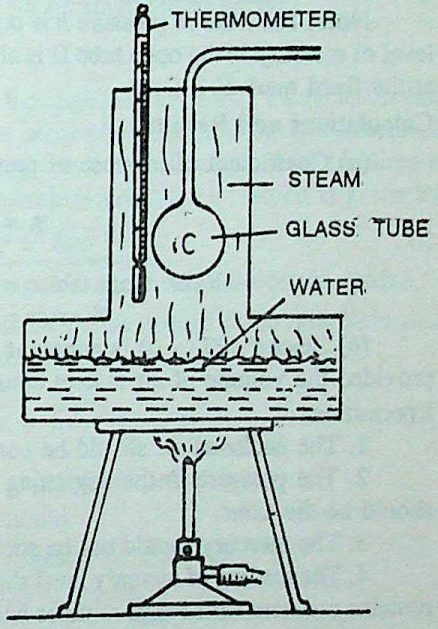

Fig. 17.3

7. Note the atmospheric pressure again and find the temperature of steam at this pressure.

8. Repeat the experiment when the air in the bulb is kept at three other temperatures say at 40°C, 60°C and 80°C etc.

Observations

Atmospheric pressure in the beginning = ... cm of Hg
Atmospheric pressure at the end = ... cm of Hg
Mean atmospheric pressure H = ... cm of Hg
= ..... mm of Hg
Temperature of steam = t_2 = 100 – ·0367 (760 – H)
= ..... °C.

where H is the atmospheric pressure in **millimetres of mercury.**

Reading of the mercury level at the fixed mark F = ... cm

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Temperature (t)	Mercury level reading in open tube D (y)	Head of pressure $\pm(y-x)=\pm h$	Pressure of air (P) = H±h (cm of Hg)	$\frac{P}{(273+t)}$
0°C			P_0 =	
40°C			P_{40} =	
60°C			P_{60} =	
80°C			P_{80} =	
t_2°C =.....°C (Steam point)			P_2 = (at steam point)	

Note. The head of pressure h is positive or negative according as the level of mercury in the open tube D is above or below the level of mercury at the fixed mark F.

Calculations and Results :

(a) Coefficient of increase of pressure at constant volume

$$\gamma_v = \frac{P_2 - P_0}{P_0 \times t_2} = \text{.....}$$

Value from tables = 0·00367

% error = ...

(b) Since P/(273 + t) is constant ; thus it is established that $P \propto T$ provided the volume of air is kept constant.

Precautions

1. The enclosed air should be completely dry.
2. The pressure in the beginning and at the end of the experiment should be the same.
3. The mercury should not be sticking to the sides of the glass tube.
4. The reading of mercury level should be taken when the temperature remains constant for several minutes and the mercury remains at the fixed point F.
5. The open tube should be considerably lowered after the reading at the steam temperature has been taken otherwise mercury will rush into the bulb when the burner is removed.
6. The bulb should be surrounded by steam and should not be immersed in water.
7. The bulb should be completely surrounded by pounded ice.

Sources of Error

1. Glass bulb expands and the volume of air increases, the volume, therefore, does not remain constant.
2. The air in the capillary tube is not at the same temperature as the air in the bulb.
3. The enclosed air may not be completely dry.

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EXPERIMENT 18

To determine the coefficient of viscosity of a given liquid by plotting a graph between terminal velocity and square of radius of spherical body.

Apparatus :

A tall wide-mouthed glass jar ; transparent liquid (glycerine) ; steel ball bearings of *different* sizes ; metre-scale ; vernier callipers ; screw gauge ; stop-watch ; watch glass ; a sensitive thermometer.

Theory :

This experiment is based on the application of Stoke's Law to the fall of spheres through a liquid. It was shown by Stokes's that if a sphere of radius 'r' is allowed to fall through a viscous liquid, it soon acquires a **constant** velocity known as the **terminal velocity** 'V' which is given by

$$\boxed{F = 6\pi\eta\, rV} \qquad \ldots (i)$$

where F is the viscous drag tending to resist the motion of the sphere.

In the steady state F is equal to the downward force which, in this case, is the apparent weight of the sphere in the liquid. Thus

$$6\pi\eta\, rV = \frac{4}{3}\pi r^3 (\rho - d)\, g \qquad \ldots(ii)$$

where ρ = density of the material of the sphere

d = density of the liquid

η = coefficient of viscosity of the liquid

g = Acceleration due to gravity

From (*ii*) it is clear that

$$\frac{V}{r^2} = \text{constant} \qquad \ldots(iii)$$

or $\boxed{V \propto r^2}$ *i.e.*, the terminal velocity varies as (radius)^2.

Coefficient of viscosity $(\eta) = \frac{2}{9}\frac{r^2}{V}(\rho - d)\, g$

Procedure :

1. Take a long wide-mouthed cylindrical glass jar and fill it with glycerine (experimental liquid).

2. Slip some thin paper collars (such as P, Q, R) round the glass jar (Fig. 18.1).

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3. Now take some steel bar bearings and measure their diameters with screw gauge.

4. Place the steel ball-bearings in a small amount of the experimental liquid in a watch-glass. Roll them in the liquid till their surfaces are thoroughly wetted.

5. Transfer a ball to the glass jar and when it has dropped a few centimetres, start a stop-watch to obtain its terminal velocity by timing a measured fall. To avoid error due to parallax, use upper edges of the paper collars as points of reference for this determination. **Do not pick up the ball with the hand. It should preferably be done with the help of the blade of a knife.**

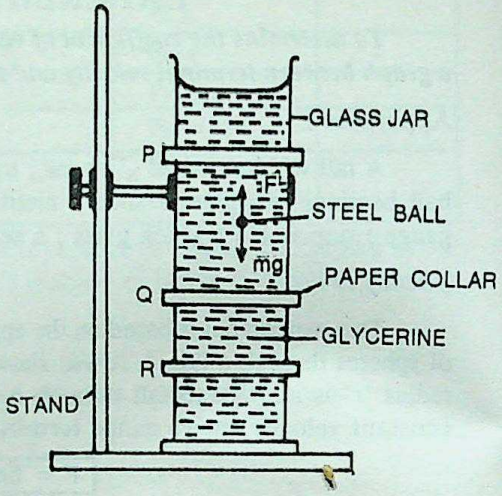

Fig. 18.1

6. Use seven or eight balls of different sizes available and allow them to drop through the liquid one after the other in quick succession to ensure identical temperature conditions.

7. Measure with a metre-scale the distance between successive paper collars and thus knowing the time of fall for a measured distance. Calculate the terminal velocity.

8. Plot a graph between terminal velocity (V) and r^2 for ball-bearings of various sizes which will be a straight line (Fig. 18.2). From the graph, find the terminal velocity (V) for a particular value of r^2 and hence calculate the co-efficient of viscosity (η).

Observations and Calculations :

Acceleration due to gravity at ..... (Place)

= g = ... cm s^{-3}

Temperature of the liquid = ...°C.

Density of the liquid (from tables) = d = ... g cm^{-3}

Density of the spherical body (steel) = ρ = ... g cm^{-3}

Least count of screw gauge = ... cm

Zero error of screw gauge = ... cm

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Steel ball bearing No.	Diameter				Radius (r) (cm)	r^2 (cm^2)	Distance between two paper collar (s) (cm)			Time of fall (t) in seconds			Terminal velocity $V = \frac{s}{t}$ cms^{-1}
	Observed			Corrected (cm)									
	(i)	(ii)	Mean				(1)	(2)	Mean	(i)	(ii)	Mean	
1.													
2.													
3.													
4.													
5.													
6.													
7.													
8.													

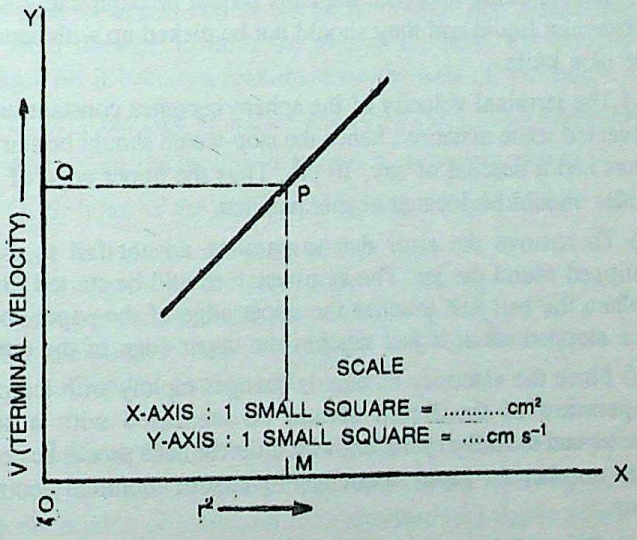

Fig. 18.2

From the graph (Fig. 18.2)

$OM = r^2 = \ldots\ldots\ cm^2$

$OQ = V = \ldots\ldots\ cm\ s^{-1}$

Coefficient of viscosity (η) of the given liquid (glycerine)

$$= \frac{2}{9} \cdot \frac{r^2}{V} (\rho - d)\, g$$

$= \ldots\ldots$ poise

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Coefficient of Viscosity of glycerine from the tables = 8.5 poise

% error = ...

Results :

(*a*) Co-efficient of viscosity of the given liquid (glycerine) as determine by the experiment = ... poise at ..... °C.

(*b*) A graph between terminal velocity (V) and $(\text{Radius})^2$ of steel ball-bearings is a straight line, *i.e.*, terminal velocity is directly proportional to $(\text{radius})^2$.

Precautions and Sources of Error :

(*i*) The radius of the ball-bearing is a very small quantity, hence it should be measured very accurately with a fine micrometer screw. During this determination the back-lash error of the screw should be avoided.

(*ii*) The ball-bearings should be dropped centrally in the glass jar, so that they are far removed from the walls.

(*iii*) Before being dropped, the balls should be completely wetted in the experimental liquid and they should not be picked up with hand but on the blade of a knife.

(*iv*) The terminal velocity of the sphere becomes constant only after it has traversed some distance ; hence the stop-watch should be started only after it has had a descent of say, 10 cm. Thus the upper edge of the first paper collar should be located at this position.

(*v*) To remove the error due to parallax do not fail to use paper collars slipped round the jar. The stop-watch should be started just at the instant when the ball just touches the upper edge of the paper collar and should be stopped when it just touches the upper edge of the other one.

(*vi*) Since the viscosity of liquids changes rapidly with temperature, the temperature of the liquid should be measured with a sensitive thermometer and the fall-experiment with different balls should be performed one after another in rapid sequence to ensure identical temperature conditions.

(*vii*) The chief sources of error in this experiment is the lack of arrangement to ensure perfect constancy in temperature of the liquid throughout the experiment.

ORAL QUESTIONS

Q. 1. *What do we mean by viscosity of a liquid ?*

Ans. Viscosity of a liquid is that property by virtue of which it opposes relative motion between its different layers. Hence, if a layer of glycerine slips over another which is at rest, the latter exerts a dragging force on the former, so that there is a tendency of the relative motion

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between the two being destroyed. The property which brings about this is known as *viscosity.*

Q. 2. *Define coefficient of viscosity of a liquid.*

Ans. The coefficient of viscosity of a liquid is defined as the tangential force per unit area required to maintain a unit velocity gradient between two layers in the liquid.

Q. 3. *What are the dimensions of coefficient of Viscosity ?*

Ans. $M^1L^{-1}T^{-1}$.

Q. 4. *What is streamline motion ?*

Ans. Streamline motion of a liquid is that orderly type of motion in which the liquid stream may be divided into parallel layers which flow past one another with various velocities. Thus when the flow of water in a capillary tube is stream-lined, it means that the layer in contact with the wall of the tube is at rest and as we move away from the wall towards the axis of the tube, the velocity uniformly increases till it becomes maximum on the axis of the tube.

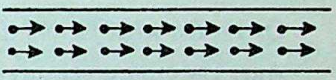

Fig. 6.3. Streamline motion

Q. 5. *What type of motion ensures if there is no streamline motion ?*

Ans. Then the motion is known as turbulent motion.

Q. 6. *What is the distinguishing feature of turbulent motion ?*

Ans. In this case the paths of the individual particles are *no longer rectilinear*, but contiguous layers even go on intermixing so that in the body of the liquid *eddies* are formed.

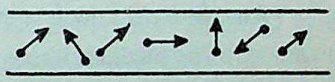

Fig. 6.4. Turbulent flow

Q. 7. *Upon what factors does the starting of turbulent motion depend ?*

Ans. For every liquid there is a certain limiting velocity below which the motion of the liquid is streamlined and above which turbulence sets in. This limiting velocity of a liquid is known as **critical velocity.**

Q. 8. *Is there any effect of temperature on the viscosity of liquids ? If so, what ?*

Ans. Yes, The viscosity of liquids generally *falls* with temperature, but there is no satisfactory formula connecting the two. The change is *considerable.*

Q. 9. *What is Poise ? Define it.*

Ans. *Poise* is the unit in which the coefficient of viscosity is expressed. It can be defined as that value of the coefficient of viscosity which is

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attained by a liquid when unit tangential force is required per unit area to maintain unit relative velocity between the two layers situated unit distance apart.

$$\left[F = -\eta A \cdot \frac{dV}{dx} \; ; \; \eta = 1 \text{ poise if } F = 1 \; ; \; A = 1 \text{ and } \frac{dV}{dx} = 1\right]$$

Q. 10. *What is the effect of pressure on the viscosity of liquids ?*

Ans. The effect of pressure is very much complicated. With fairly mobile liquids the effect of pressure on viscosity is not very marked. For instance, when ether at 20°C is subjected to an increase of pressure by 500 atmospheres, its viscosity is *raised* by about 60%. With water, however, the viscosity *decreases* for the first few hundred atmospheres, thereafter, it *increases.*

Q. 11. *On what factors does critical velocity depend ?*

Ans. The critical velocity of a liquid depends upon (*a*) density of the liquid, (*b*) radius of the tube and (*c*) coefficient of viscosity.

Q. 12. *What is Stoke's Law ?*

Ans. *Stokes* showed that the *retardation* F, due to the *viscous drag,* for a spherical body of radius '*r*', moving with a constant velocity V, in a medium whose coefficient of viscosity is η, is given by

$\boxed{F = 6\pi\eta\, rv}$. This relation is known as *Stoke's Law.*

Q. 13. *What are the limitations of Stoke's Law ?*

Ans. Stoke's Law is applicable only :

(*i*) The medium through which the body falls is *infinite in extent.*

(*ii*) The spherical body is *perfectly rigid and smooth.*

(*iii*) There is no slip between the spherical body and the medium.

(*iv*) The medium is *homogeneous* so far as the spherical body is concerned *i.e.,* the diameter of the spherical body is large compared with the spaces between the molecules of the medium.

(*v*) There are no *eddy currents* or *waves set up in the medium* due to the motion of the body through it. In other words, the body is moving very slowly through it.

Q. 14. *What is terminal velocity ?*

Ans. When a body falls through a viscous medium, its motion is opposed by a force, frictional in nature. Now, this opposing force, increases with the velocity of the body, until in the case of small bodies, it becomes just equal to the *driving force* and the body then attains a constant velocity, called its *terminal velocity.*

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Q. 15. *When does the falling sphere acquire a terminal velocity ?*

Ans. When the viscous drag equals the *effective* weight of the sphere *i.e.*, there is no resultant force acting on the sphere, *i.e.*,

$$6\pi\eta rV = \frac{4}{3}\pi r^3 (\rho - d)\, g$$

Q. 16. *Why should the ball-bearings be centrally dropped in the glass jar ?*

Ans. So that they are far removed from the walls of the glass jar otherwise the fall will be influenced by the proximity of its walls.

Q. 17. *Why are the spheres wetted in glycerine before allowing them to fall through the glycerine ?*

Ans. To avoid the formation of air bubbles.

Q. 18. *Why should the experiment with various spheres be carried out quickly one after another ?*

Ans. To ensure identical temperature conditions.

Q. 19. *Why do tiny rain drops remain suspended in the air and appear to us to be floating about as clouds whereas bigger rain drops fall through the air ?*

Ans. Tiny drops of water have a radius as small as 0·001 cm and their terminal velocity, as they fall through air, for which $\eta = 0{\cdot}00018$, comes to about 1·2 cm/sec. That is why they remain suspended in the air and appear to us to be floating about as clouds.

Bigger rain drops, on the other hand, have a radius about 10 times as great (*i.e.*, 0·01 cm) and their terminal velocity, therefore, comes to about 120 cm/sec, so that they fall through the air instead of floating in it.

Q. 20. *Why do bubbles of air or gas rise up through water or any other liquid ?*

Ans. If the density of the medium in which the body falls be greater than that of the body itself, it is clear that the terminal velocity 'V' will have a *negative* value. In such a case, therefore, the body will have an *upward terminal* velocity. That is why bubbles of air or gas can rise up through water or any other liquid. The smaller the bubble, the smaller its velocity.

□□

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EXPERIMENT 19

To study graphically the stress-strain relationship for a steel wire using Searl's Apparatus and to determine the Young's Modulus for it.

Apparatus :

Searl's apparatus with steel wire, Screw gauge, Metre-rod, Slotted weights with hanger.

Formula employed :

The Young's Modulus (Y) for the material of a wire is given by

$$Y = \boxed{\frac{MgL}{\pi r^2 l}} \text{ dyne cm}^{-2}$$

where
M = mass suspended from the wire ;
L = original length of the wire ;
r = radius of the wire ;
l = change in length of the wire.

Theory :

If a wire of length 'L' has a load of 'M' g suspended from its lower end, then a force equal to Mg dynes acts vertically along the axis of the wire and consequently the wire extends in length a little. Let this extension be 'l' cm. Then the longitudinal strain produced in the wire is l/L. If the area of cross-section of the wire be A, then the normal stress set up in the wire in the equilibrium state is given by Mg/A. Then, from definition, the Young's Modulus is given by

$$Y = \frac{\text{Longitudinal Stress}}{\text{Longitudinal Strain}} = \frac{Mg / A}{l / L} = \frac{Mg \,.\, L}{A \,.\, l}$$

If the radius of the wire be 'r', then $A = \pi r^2$

and
$$Y = \frac{Mg \,.\, L}{\pi r^2 \,.\, l}$$

Procedure :

(*i*) First of all determine the pitch and the least count of the micrometer screw. Hang the hanger 'H' in the hook 'B' of the frame F_2 connected to the experimental wire 'b' to remove any kinks present in it and to keep it*

*If this is not done the values of the first few extensions shall be erroneous.

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taut. Also suspend the dead weight 'W' from the other hook A to keep the reference wire '*a*' straight.

Now without taking any readings add a few weights, one-by-one, then remove them one-by-one. This *operations should be repeated twice or thrice and care should be taken that the weights are placed gently.

(*ii*) Find the diameter of the wire '*b*' with the screw gauge at six different places. At each point, measure the diameter in two mutually perpendicular directions.

(*iii*) Now by turning micrometer screw (M) bring the air bubble of the spirit level in the centre and note the reading on the pitch scale and the disc scale.

(*iv*) Calculate the **breaking** load and hence permissible load for the given steel wire by the formula.

Breaking load = Breaking stress × area of cross-section in cm^2

∴ **Permissible load = 1/2 of the calculated breaking load.

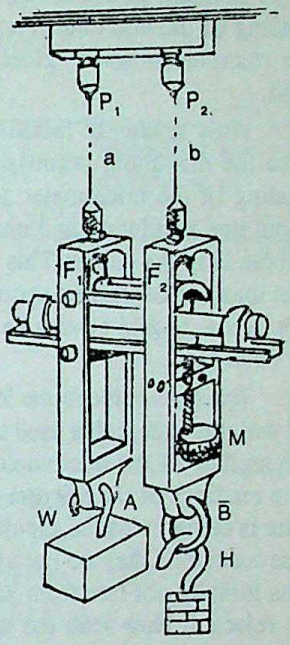

Fig. 19.1. Searle's apparatus

Do not place the load on the wire more than the permissible load to keep the wire within elastic limits.

(*v*) †Place gently half a kilogram weight in the hanger H and wait for about two minutes. This will result in the extension of the wire and

*A wire shows some irregularity in extension when it is loaded for the first time ; but when the loading and unloading is carried on for some time, the wire attains a steady state and the behaviour regarding extension becomes uniform. This indicates that the wire which is strained for the first time must have developed a structural change in itself which could not recover for sometime. This has been verified by taking photographs of the sections of a wire before and after loading where a remarkable change in the surface structure has been revealed. This property of the wires is generally named "Elastic Fatigue".

**Hooke's Law is valid within "Elastic Limit" only. Hence under no circumstances should the wire be loaded with more than the maximum possible load and this permissible load is given by half the breaking stress for the wire, since this elastic limit ensues just after the application of this stress.

†For instance, for one particular steel wire the radius was found to be 0·22 cm. Hence the area of cross-section of the wire = $\pi r^2 = (3{\cdot}14 \times 0{\cdot}22)^2 = 0{\cdot}00152$ cm^2. From the table of constants, breaking stress for steel = 110×10^8 dyne/cm^2. Hence breaking load = $0{\cdot}00152 \times 110 \times 10^8$ dyne = 16 kg (nearly). Therefore load greater than 8 kg should not be applied to this particular wire.

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consequently the air bubble will get displaced. Bring back the air bubble in its standard position, *i.e.*, the centre by raising the screw and note the reading of the micrometer screw. The difference between two readings of the micrometer screw gives the extension produced by half-a-kilogram load.

Now gradually increase the load in equal steps of half-a-kilogram upto the maximum permissible load, adjust the spirit level and note the reading of the micrometer screw each time. Move the screw forward by about one revolution and note its reading again by turning it back till the bubble is in the centre. This reading will be nearly or exactly equal to the previous one depending upon the amount of back-lash present in the screw. The screw should always be moved in **one direction to avoid error due to back-lash.**

(*vi*) Now remove the load in steps of one half-a-kilogram weight till all weights except that used to keep the wire taut have been removed. Take the reading of the micrometer screw after each weight has been removed. The readings of the micrometer screw for various weights taken when the wire is being unloaded should agree closely with those taken when the wire was loaded. If they do not agree, then it means that the experimental wire was initially not free from kinks and hence this set of observations should be rejected. Now load the wire with heavier weight to remove the kinks and repeat the process till a satisfactory set of readings is obtained.

(*vii*) Measure the length of the expeimental wire '*b*' from the point of support to the pin-vices, *i.e.*, to the place where the wire is fixed to the rectangular frame.

(*viii*) Now take the mean of the two readings of the micrometer screw for the same load and calculate the mean extension of the wire as given in observation table. The reading for this purpose should be so coupled that no reading is used twice otherwise that reading will become useless when the mean is taken.

(*ix*) Plot a graph between load and extension taking load along the X-axis and extension along Y-axis with suitable scales. It will be a straight line showing that extension is proportional to load which is Hook's Law. Calculate extension for a definite load from the graph and determine Young's Modulus 'Y'.

***Observations and Calculations :**

Pitch of the screw gauge = 1 mm

No. of divisions on the circular scale = 100 div.

---

*Students should carefully note that the reading entered herein were obtained for a particular wire. They should enter here the *actual values* obtained by them in their laboratory.

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Least count of the screw gauge = $\frac{1}{100}$ = 0·01 mm = 0·001 cm

Zero correction of the screw gauge = 0·0 mm

Diameter of the Wire :

S. No.	Reading along any diameter in mm	Reading along a perpendicular diameter in mm	Mean corrected diameter in cm
1.	0·64	0·65	
2.	0·64	0·64	
3.	0·65	0·65	0·0644
4.	0·65	0·64	
5.	0·65	0·64	
6.	0·64	0·64	

Radius of the experiment wire 'r' = 0·0322 cm

Pitch of the micrometer screw = 1·0 mm

No. of division on the head scale = 100 div

Least count of the micrometer screw = 0·01 mm

Extension of the Wire :

S. No.	Weight in the hanger 'H' in kg	Micrometer Screw readings in mm			Extension for 2 kg in mm	Mean extension (l) for 2 kg in cm
		Loading (x)	Unloading (y)	Mean $\left(\frac{x+y}{2}\right)$		
1.	0·0	1·03	1·03	1·03 (a)		
2.	0·5	1·33	1·34	1·34 (b)	1·27	
3.	1·0	1·65	1·64	1·64 (c)	1·29	
4.	1·5	1·98	1·99	1·98 (d)	1·28	0·1275
5.	2·0	2·28	2·32	2·30 (e)	1·26	
6.	2·5	2·62	2·65	2·63 (f)		
7.	3·0	2·94	2·90	2·92 (g)		
8.	3·5	3·24	3·24	3·24 (h)		

Length of the wire (L) = 259·5 cm

$\therefore$ Young's Modulus 'Y' = $\frac{Mg \cdot L}{\pi r^2 \cdot l}$

$= \frac{2 \times 1000 \times 981 \times 259 \cdot 5}{3 \cdot 14 \times (0 \cdot 0322)^2 \times 0 \cdot 1275} = \frac{2 \times 981 \times 2595}{314 \times (322)^2 \times 1275} \times 10^{10}$

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$$\log Y = \log 2 + \log 981 + \log 2595 + 10 \log 10 - \log 314 - 2 \log 322 - \log 1275$$

$$= 0{\cdot}3010 + 2{\cdot}9917 + 3{\cdot}4142 + 10{\cdot}0 - 2{\cdot}4968 - 5{\cdot}0159 - 3{\cdot}1055$$

$$= 22{\cdot}7069 - 10{\cdot}6182 = 12{\cdot}0887$$

$$\therefore \quad Y = 12{\cdot}27 \times 10^{11} \text{ dyne/cm}^2$$

$$= 12{\cdot}3 \times 10^{11} \text{ dyne/cm}^2$$

Graph :

Average value of extension (l) for 2 kg from the graph = 0·1270 cm

$$\therefore \qquad Y = \frac{Mg \,.\, L}{\pi r^2 \,.\, l} = 12{\cdot}3 \times 10^{11} \text{ dyne cm}^{-2}$$

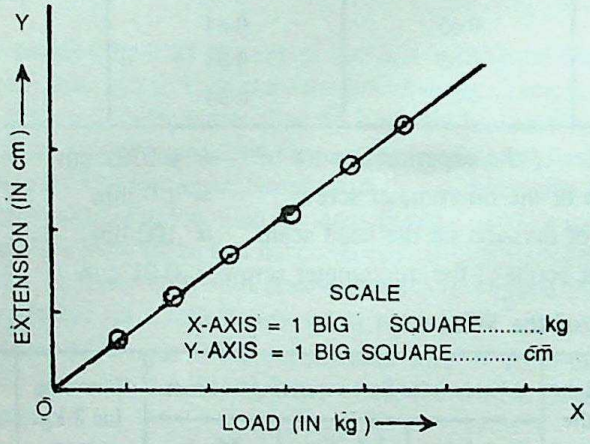

Fig. 19.2.

Result :

Young's Modulus of Elasticity (Y) for the given *copper* wire

$$= 12{\cdot}3 \times 10^{11} \text{ dyne cm}^{-2}$$

Actual value from the table $= 12{\cdot}4 \times 10^{11}$ dyne cm^{-2}

$$\therefore \qquad \% \text{ Error} = \frac{\text{Difference}}{\text{Actual value}} \times 100\%$$

$$= 0{\cdot}8\%.$$

Precautions :

1. There should not be any kinks in the wire. It should be loaded heavily at the start to remove the kinks as described in the procedure.

2. The wire should not be loaded beyond elastic limits.

3. The loading or unloading should be in equal step (1/2 kg) and should be done carefully and gently.

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After each addition or removal of the load, wait for two minutes in order to allow (*i*) the wire to increase or decrease in length, (*ii*) the oscillations to subside and, (*iii*) the wire to attain the room temperature.

4. The radius of the wire should be determined at various points and at each point in two mutually perpendicular directions. This is because a small error in the measurement of '*r*' will result in a larger error in the value of Young's Modulus.

5. While calculating the extension from the mean readings of the micrometer screw for various loads, the students are *warned against* taking differences between *the two consecutive readings*. If $a, b, c, d, \ldots\ldots, h$ be the mean of loading and unloading, the successive difference will be $(b - a)$, $(c - b)$ ..... $(h - g)$ and their mean

$$\frac{(b-a)+(c-b)+\ldots\ldots(h-g)}{7}=\frac{(h-a)}{7}$$

Therefore only first and last readings are utilised and others have been wasted. But if the mean of $(e - a)$, $(f - b)$, $(g - c)$ and $(h - d)$ is taken, all observations are utilised.

6. Before every reading of the micrometer screw, the bubble of the spirit level should be brought at the centre.

7. The micrometer screw should always be rotated in the same direction to avoid back lash error.

8. The length of the wire (L) is the length of the experimental wire '*b*' and *not* that of the reference wire '*a*'.

9. The graph should be smooth and should pass through nearby all the points.

Sources of Error :

(*i*) The weights used may not be standard weights.

(*ii*) The wire may not be of uniform area of cross-section throughout its length.

(*iii*) The radius of the wire may change while loading or unloading.

ORAL QUESTIONS

Q. 1. *What is elasticity ?*

Ans. All material bodies when subjected to suitable forces, suffer a change either in size or in shape or in both and get deformed. When the deforming force is removed the body tends to come back to its original condition. This property of a body by virtue of which it regains its original condition after the removal of the deforming force is called elasticity.

Q. 2. *What are (i) Elastic bodies, and (ii) Plastic bodies ?*

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Ans. Bodies which recover completely after the removal of deforming forces are called perfectly elastic bodies and those which do not show any tendency to recover are called perfectly plastic bodies.

In actual practice, we have no perfectly elastic or perfectly plastic bodies, the difference being that of a degree.

Q. 3. *What is stress ? When is stress called (i) compressive, (ii) tensile ?*

Ans. The deforming forces applied to a body give rise to forces of reaction inside it, tending to restore it back to its original condition. This restoring force set up inside the body measured per unit area is called stress. It is equal in magnitude but opposite in direction to the applied deforming force per unit area provided the elastic limit is not exceeded.

If the deforming force is trying to press the body, the stress is named compressive stress but if the deforming force be of a nature of pull or tension, the stress is called tensile stress.

Q. 4. *What are the units of stress ?*

Ans. Its units are dynes/cm^2 in C.G.S. system ; newton/metre^2 in M.K.S. system and S.I. system.

Q. 5. *What are the dimensions of stress ?*

Ans. Its dimensions are $ML^{-1}T^{-2}$.

Q. 6. *What are the different types of stress ? Define them.*

Ans. Stress is of three kinds :

(*i*) *Longitudinal stress.* It is force per unit area which produces a change in length.

(*ii*) *Volumetric stress.* It is force per unit area which produces a change in volume.

(*iii*) *Shearing stress.* It is force per unit area which produces a change in the shape of the body.

Q. 7. *What is strain ? Mention the units of strain.*

Ans. Due to the deforming force, there is a change in the dimensions of the body. Strain is defined as the ratio of the change in configuration to the original configuration (*i.e.*, original length or volume).

Since it is a ratio, it has no units.

Q. 8. *What are the three types of strain ? Define them.*

Ans. (*i*) *Longitudinal Strain*—it is change in length per unit length.

(*ii*) *Volumetric Strain*—it is change in volume per unit volume.

(*iii*) *Shearing Strain*—it is change in shape due to relative movement of some plane of the body with respect to other. It is measured by the angle through which a side is turned.

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Q. 9. *Which comes first—stress or strain ?*

Ans. Stress depends upon strain, *i.e.*, strain is an independent quantity. This is because unless deformation is produced there is no restoring force set up inside the body.

Q. 10. *What is elastic limit ?*

Ans. The limit upto which extension is proportional to the tension and the body regains its original position after the deforming forces have been removed, is called elastic limit.

Q. 11. *What is yield point ?*

Ans. The yield point is the point at which the wire begins to flow, thinning uniformly even without any increase in the load.

Q. 12. *What is breaking point ?*

Ans. After yield point, a stage is reached when the wire goes on increasing in length and ultimately breaks. The point where it breaks is called breaking point.

Q. 13. *What is breaking stress ?*

Ans. The minimum load with which the wire breaks is called breaking load. Breaking load per unit area is called breaking stress.

Q. 14. *What is stress-strain curve ?*

Ans. Suppose a wire of uniform area of cross-section is suspended from a rigid support and is stretched by hanging a load at the other end. If the load is increased gradually, the length of the wire also increases accordingly. If the values of stress and corresponding strain are determined at various stages and a graph is plotted between them, then the stress-strain, curve is obtained as shown in Fig. 19.3.

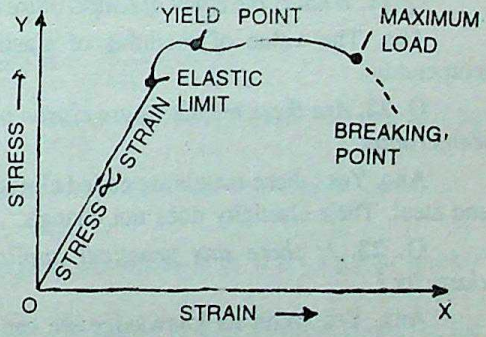

Fig. 19.3

Q. 15. *What is Hooke's Law ? Who stated Hooke's Law ?*

Ans. According to Hooke's Law, stress is proportional to the strain, within the elastic limits.

Robert Hooke stated this law.

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Q. 16. *What is Young's Modulus of Elasticity ? What are its units ?*

Ans. Young's Modulus (Y)= $\frac{\text{Longitudinal Stress}}{\text{Longitudinal Strain}} = \frac{F/a}{l/L}$

where F = force applied, a = area ; l = change in length ; L= original length

Units : C.G.S. $\rightarrow$ dyne/cm^2

S.I. $\rightarrow$ N/m^2

Q. 17. *What is meant by tensile strength ?*

Ans. It is the value of breaking stress per sq mm area of cross-section.

Q. 18. *What is permanent set ?*

Ans. If we increase the load beyond elastic limit and then the deforming forces are removed, the wire does not regain its original position but attains a permanent extension. This is called permanent set.

Q. 19. *What is elastic fatigue ?*

Ans. When two wires, one quite new and other an old one which has suffered many strains, are made to oscillate together, the older one comes to rest earlier. The older wire is said to have elastic fatigue.

Q. 20. *What do you mean by elastic after-effect ?*

Ans. When the deforming forces are removed, the body takes time to come back to its original condition. This delay is called elastic after-effect.

Q. 21. *What is the effect of temperature on the modulus of elasticity ?*

Ans. The value of modulus of elasticity decreases with rise of temperature.

Q. 22. *Are there metals whose elastic properties do not change with temperature ?*

Ans. Yes ; these metals are called **elinvars** which are alloys of nickel and steel. Their elasticity does not change.

Q. 23. *Is there any practical application of the knowledge of elasticity ?*

Ans. Yes, With its knowledge we can calculate the force which a girder or the piston rod of steam engine, etc., can withstand.

Q. 24. *Which is more elastic—steel or rubber ?*

Ans. If equal forces are applied to steel and rubber, less strain is produced in steel than rubber. Therefore steel is more elastic than rubber.

Q. 25. *Why do we use long wires ?*

Ans. So that the extensions may be large and may be measured accurately.

Q. 26. *Why do we use two similar wires ?*

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Ans. To avoid error due to yielding of the support and increase in length due to change in room temperature.

Q. 27. *Why do we wait before taking reading after each loading and unloading ?*

Ans. So that the wire may cool down to its original temperature and to allow the wire to increase or decrease in length.

Q. 28. *On what factors 'Y' depends ?*

Ans. It depends upon (*i*) the nature of the material of the body, (*ii*) form in which the body is taken and, (*iii*) temperature of the body.

Q. 29. *Does 'Y' depend on the diameter of the wire ?*

Ans. No ; it does not depend upon the diameter. It depends on nature of the material.

Q. 30. *Which measurement should be most accurate ?*

Ans. Change in length (*l*) and the radius of the wire (*r*). A small error in the measurement of '*r*' results in a large error in the value of 'Y' because $Y = \frac{Mg \cdot L}{\pi r^2 \cdot l}$.

Q. 31. *What is Poisson's ratio ?*

Ans. Poisson's ratio is defined as the ratio of lateral contraction to the longitudinal extension when a wire is stretched in a linear direction. If L and D be the initial length and diameter respectively and *l* and *d* be the increase in length and decrease in diameter, then

$$\text{Poisson's ratio } \sigma = \frac{d/D}{l/L} = \frac{L \cdot d}{l \cdot D}.$$

Since it is a ratio of two similar quantities, it has no units and no dimensions.

Q. 32. *Why is it advised to rotate the screw in the same direction ?*

Ans. To avoid backlash error.

Q. 33. *Is there any change in the value of 'Y' if a larger or thicker wire is used ?*

Ans. Yes. Young's Modulus of a wire is directly proportional to the length of the wire and inversely proportional to the area of cross-section of the wire.

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*EXPERIMENT 20

To determine the spring constant of a given spring.

Apparatus :

Light spiral spring, metre scale, two clamps and stand pointer for spring, hanger with slotted weights.

Theory :

The shape of a body changes when an external force is applied. Molecular forces tend to oppose this change. As soon as external force is removed, the body regains its original shape, if the applied force is within the elastic limit.

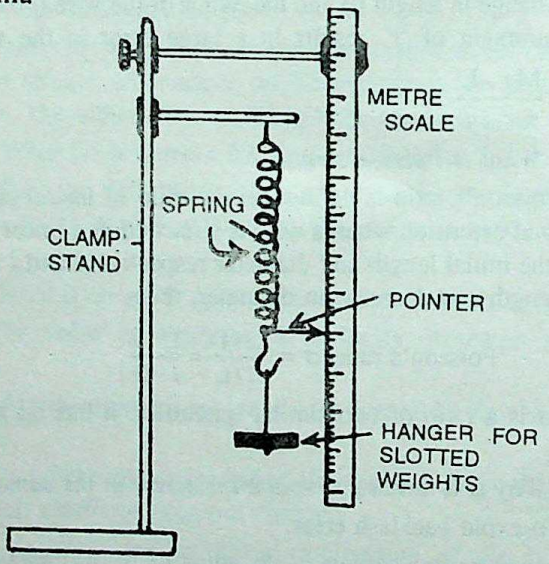

Fig. 20.1

The relationship between the extension in a helical spring and the applied force was first investigated by Robert Hooke and is known as Hooke's Law. Hooke's Law states that for a helical spring or other elastic material, the extension is directly proportional to the applied force, provided the elastic limit is not exceeded. The elastic limit is the point at which the spring or other material becomes permanently deformed. For forces applied up to the elastic limit the spring returns to its original length or shape when the forces is removed.

*Not to be given as an Experiment. It is included in the list of activities.

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$$\therefore \quad F \propto e$$

where F = applied force and e = extension

$$F = \text{constant } e$$

or $F = Ke$ where K = spring constant

$$\therefore \quad \text{Spring constant} = K = \frac{F}{e} = \frac{\text{Force}}{\text{extension}} = \frac{mg}{e}$$

where m = mass

g = acceleration due to gravity. SI unit of spring constant is Nm^{-1}

Procedure :

1. Set up the apparatus as shown in Fig. 20.1.

2. Fix a pin to the lower end of the spring to act as a pointer and record the position of the pointer on the metre scale when no force is applied.

This arbitrary zero position should be checked at the end of the experiment to ensure that the maximum force applied to the spring did not exceed the elastic limit.

3. Attach a weight hanger (which applies a known force F = 0·5 N to the spring) to the lower end of the spring. When the spring stops oscillating, record the new position of the pointer. The difference in the two readings gives the extension e which can be recorded in mm.

4. Add slotted weights of, say 0·5 N (50 g) each to the hanger (also of weight 0·5 N) so that the force can be increased from 0 to 3 N **in equal steps** of 0·5 N.

As you add each weight to the spring, note the reading of the steady pointer on the metre scale.

It is good practical technique also to take the pointer readings as the weights are removed so that an average pointer reading can be used to calculate the extension of the spring.

5. The results can be tabulated as shown below. A calculation of the ratio $\frac{F}{e} = \frac{\text{Force}}{\text{extension}}$ show it to be constant within the limits of experimental error.

6. Plot a graph between force applied and the corresponding extension. It should be a straight line passing through the origin. This demonstrates that force applied is directly proportional to the extension. From the graph, calculate K. This is $\frac{b}{a}$ (See Fig. 20.2).

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Observations and Calculations :

S. No.	Force (F) in N	Pointer reading in mm			Extension (e) in mm for .....N	Spring constant $K = \frac{F}{e}$ (in Nmm^{-1})
		Loading	Unloading	Mean		
1	0			A		
2	0·5			B	(D–A)=...mm	
3	1·0			C	(E–B)=...mm	
4	1·5			D		
5	2·0			E	(H–C)=...mm	
6	2·5			H	(G–D)=...mm	
7	3·0			G		
				Mean Value of e =	.....mm	

From the graph (Fig. 20.2) ;

The elastic constant of spring $K = \frac{b}{a}$ = ... N/mm

= ..... N/m

Result :

(1) K=.....Nm^{-1} is the force applied on the spring per metre extension.

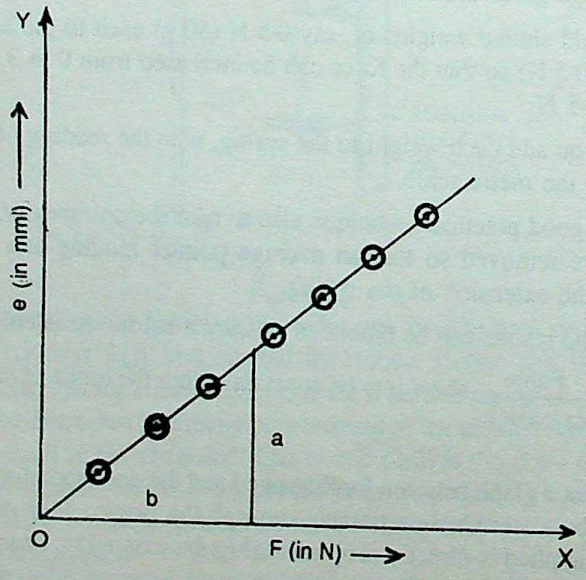

Fig. 20.2

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2. Since the graph of F against e is a straight line passing through the origin, then the extension of the spring is directly proportional to the tension in the spring (Hooke's law).

Precautions :

1. The spring should be suspended in such a way that its axis is vertical and the scale should be adjusted parallel to its axis.

2. The spring should not be loaded beyond elastic limits.

3. The loading or unloading should be in equal steps and should be done carefully and gently. After each addition or removal of the load, wait for 1 minute in order to allow (*i*) the spring to increase and decrease in length and (*ii*) the oscillations to subside.

4. The pointer should be so adjusted that it is not just touching the scale, otherwise it will rub against the latter and correct reading of extension shall not be obtained.

Sources of Error :

1. The weights used may not be standard weights.

2. Error may occur in reading the pointer positions.

ORAL QUESTIONS

Same as in Experiment 19.

□□

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EXPERIMENT 21

To find the spring constant of a helical spring by measuring time period of vertical oscillations of a known load and check by measuring its extension by a known force.

Apparatus :

A helical spring, metre scale, two clamps and stands, stop-watch, light pointer for spring, hanger with slotted weights, 1 kg weight.

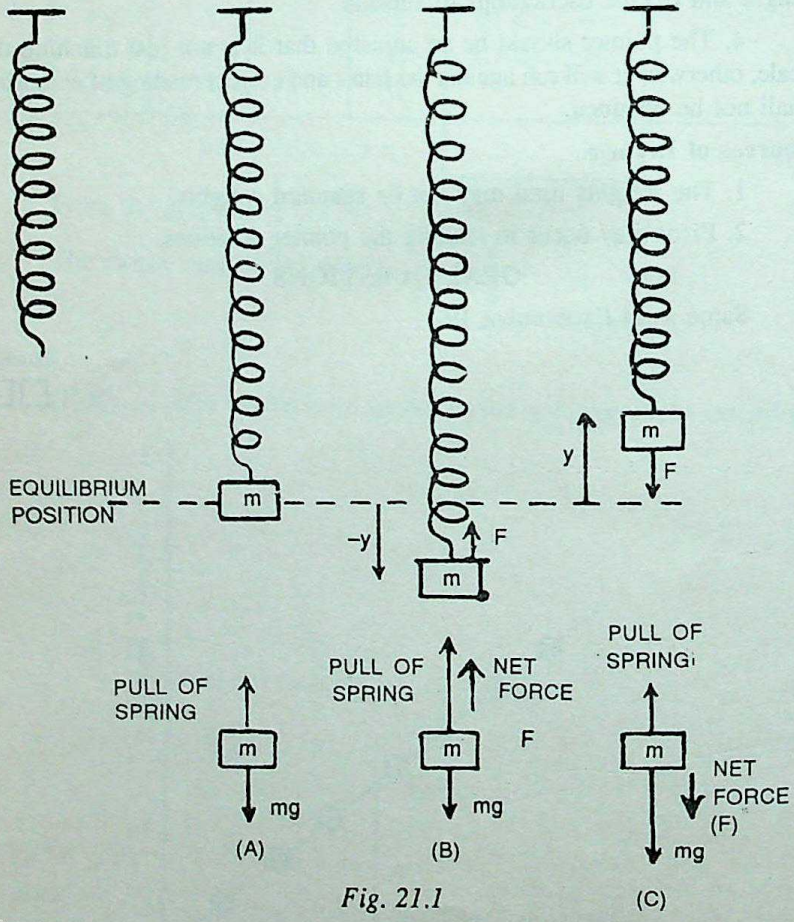

Fig. 21.1

Theory :

If a mass is oscillating back and forth with simple harmonic motion, there must be a force acting. For example, you hang a mass carefully on

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a spring, letting it hang at rest. If the mass is pulled down as in Fig. 21.1, the spring pulls it back toward its equilibrium position. If the mass is lifted slightly, gravity tends to pull it down. Whenever the mass is displaced, there is a force pulling it back to the equilibrium position. If the displacement is up (positive), the restoring force is down (*negative*). If the displacement is down (negative), the restoring force is upward (*positive*). The restoring force is opposite in sign to the displacement.

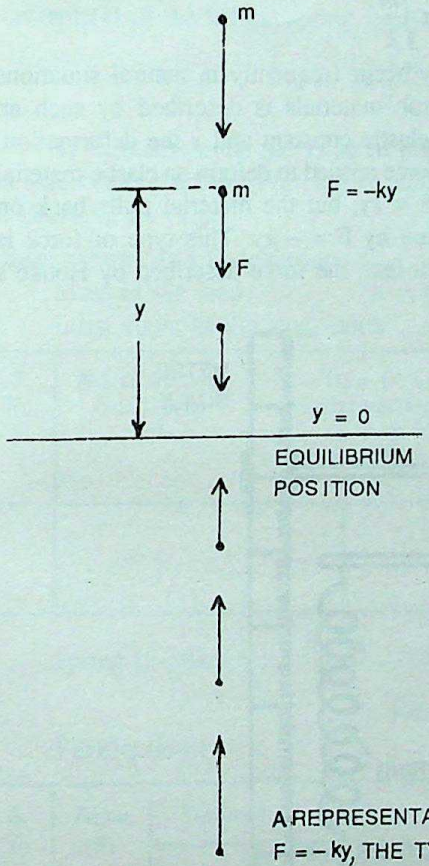

Fig. 21.2

The force is related to the acceleration by Newton's Second Law, $F = ma$. In simple harmonic motion, the acceleration is described by

$$a = -\omega^2 y, \text{ where } y \text{ is the displacement.}$$

Applying Newton's Second Law,

$$F = ma = -m\omega^2 y$$

This is of the form $F = -ky$

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where $$k = m\omega^2 = \frac{4\pi^2 m}{T^2}.$$

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These last equations form the basis for the definition of motion of the type called simple harmonic. If an object moves under the influence of a force described by $F = -ky$, then S.H.M. will result and the period will be found from the relations

$$k = \frac{4\pi^2 m}{T^2}$$

or

$$T = 2\pi\sqrt{\frac{m}{k}}$$

Forces of the form $F = -ky$ occur frequently in natural situations because the force exerted by elastic materials is described by such an equation, with k being called the elastic constant and y the deformation. The minus sign occurs because the force needed to deform an elastic material by an amount y is described by $F = ky$, but the material pulls back on whatever is producing the distortion by $F = -ky$. This type of force is illustrated in Fig. 21.2, and it is, in fact, the force described by Hooke's law.

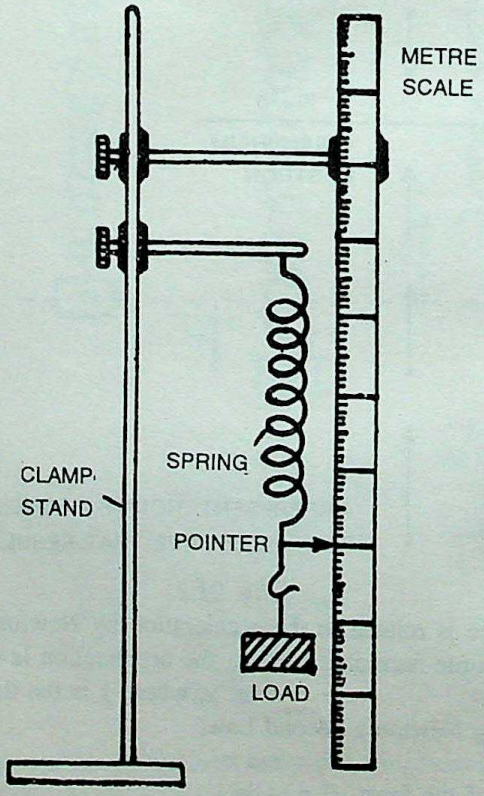

Fig. 21.2

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Procedure :

1. Set up the apparatus as shown in Fig. 21.3.

2. Attach a suitable mass (m) say 1 kg at one end of a helical spring. Suspend the spring vertically.

3. Pull the weight down through a small distance and let it go. The mass suspended by the lower end of the spring would start executing vertical oscillations. Find the time for say 10 oscillations with the help of stop-watch and then calculate its time-period (T) and hence find the spring constant (k) of the helical spring from the formula

$$T = 2\pi\sqrt{\frac{m}{k}} \qquad \text{or} \qquad k = \frac{4\pi^2 m}{T^2}$$

4. Also determine the value of the spring constant (k) by measuring its extension by a known force as explained in Expt. 20. This will help you in checking its value.

Observations and Calculations :

Mass of the load $= m =$ ..... kg

Least count of the stop-watch = ... s

S. No.	No. of vertical oscillations (n)	Time (t) for n vertical oscillations in seconds			Time Period $T = \frac{t}{n}$ in seconds
		1	2	Mean	

Spring Constant $(k) = \frac{4\pi^2 m}{T^2}$

$= \ldots\ldots\ldots \text{ Nm}^{-1}$

Verification :

S. No.	Force (F) in N	Pointer reading in mm			Extension (e) in mm	Spring constant $K = \frac{F}{e}$ (in Nm^{-1})
		Loading	Unload-ing	Mean		
					Mean Value =	

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Result :

Spring constant (k) of the given helical spring = ... Nm^{-1}

Precautions :

(1) to (4) same as in Expt. 20.

(5) While oscillating the spring see that the amplitude of oscillations is **small** and the spring oscillates in a **vertical plane.**

(6) Note the times very carefully and for this purpose employ an accurate stop-watch. The time periods occur **squared** in the formula and hence any error committed in their evaluation will introduce double the error in the results.

Sources of Error :

[Same as in Expt. 20]

ORAL QUESTIONS

[Same as in Expt. 20]

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EXPERIMENT 22

(a) To find the relation between length and tension for constant frequency and diameter of a stretched string using a sonometer.

(b) Determine the frequency of a tuning fork.

Apparatus :

A sonometer, the given tuning fork, a rubber pad, sensitive physical balance, weight box, solid kilogram weights, paper rider.

Theory :

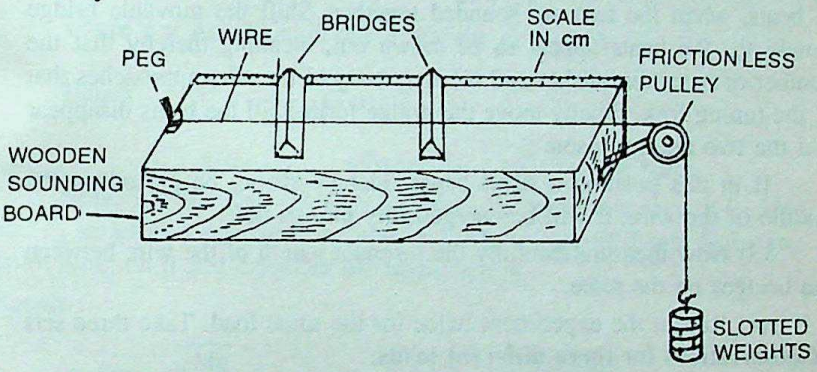

Fig. 22.1. Sonometer

When the wire of the sonometer (Fig. 22.1) having certain tension is plucked in the middle, it is thrown into stationary vibrations having nodes at the two edges of the bridges and an antinode in the middle. The volume of the note emitted by the wire is considerably increased with the help of the sounding board due to the forced vibrations imposed by the vibrating wire upon it and the air contained therein.

When the note emitted by the sounding length of the wire is **in unison** with the tuning fork, the frequency 'n' of the latter is given by

$$n = \frac{1}{2l}\sqrt{\frac{T}{m}} = \frac{1}{\lambda}\sqrt{\frac{T}{m}}$$

where λ = wave length

l = length of the vibrating segment of the sonometer wire

T = Tension applied to the wire

= Mg where M is the total mass suspended from the wire.

m = mass of the wire **per unit length.**

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Procedure :

(1) Check that the pulley of the sonometer is frictionless and then stretch the sonometer wire with a suitable known tension by placing weights on the hanger. Sound the tuning fork by gently striking it at the end of a prong against a soft rubber pad and place it on the top of the sounding box. A loud sound will be heard. Now starting with a small length of the wire between the bridge, **pluck in the middle* so as to excite its fundamental mode of vibration and compare its note with that of the tuning fork.

(2) Now shift the position of one of the bridges so as to increase the length of the sounding wire till the frequency of the tuning fork is very nearly equal to that of the wire. This will be apparent from the appearance of beats, when the two are sounded together. Shift the movable bridge slowly till the beats appear to be drawn out, meaning thereby that the number of beats diminishes and the frequency of the wire approaches that of the tuning fork. Finally move the bridge further till the beats disappear and the two are in unison.

If in this position a small paper rider (V-shape) be placed on the middle of the wire, it will be energetically thrown off.

(3) Now measure carefully the resonant length of the wire between the bridges on the scale.

(4) Repeat the experiment twice for the same load. Take three sets of observations for **three different loads.**

(In the process of increasing the load on the hanger, be careful not to stretch the wire beyond the elastic limit.)

(5) Next cut off a length (preferably one metre) of the wire, weigh it in a sensitive physical balance and thus determine its mass per unit length and then calculate 'n' from the formula given above.

Observations :

S. No.	Load applied (M) kg	Tension $T = Mg$	Length of the wire (between the bridges) in unison				Wavelength $\lambda = 2l$	$\frac{\sqrt{Mg}}{\lambda}$	l^2	Mean l^2	$\frac{Mg}{l^2}$	$n = \frac{1}{2l}\sqrt{\frac{Mg}{m}}$ (Hz)
			(1) cm	(2) cm	(3) cm	Mean (l) cm						
1.												
2.												
3.												
4.												

Mean n = ...Hz

*Avoid the use of fingernails in this process.

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Calculations :

Length of the wire= a = ... cm

Mass of length 'a' cm of wire = x = ... g

Mass per unit length = $m = \frac{x}{a}$ = ... g/cm

Now, $$n = \frac{1}{2l}\sqrt{\frac{T}{m}}$$

$$= \frac{1}{2l}\sqrt{\frac{Mg}{m}}$$

where g = Acceleration due to gravity at a place.

Hence $n^2 = \frac{g}{4m}\frac{M}{l^2}$ =.....

$\therefore$ n = ... vibs/sec (or cycles/sec) or hertz.

Note. We can also calculate 'n' from the graph between T (= Mg) and l^2, which is a straight line. From this graph read off T and l^2 for any point lying on it and calculate the frequency 'n'.

Result :

(a) Since $\frac{\sqrt{Mg}}{\lambda}$ = constant, therefore $\frac{\sqrt{\text{Tension}}}{\text{Wavelength}}$ = constant

(b) the frequency of the tuning fork

(i) as determined experimentally = ... Hz

(ii) as given on the fork itself = ... Hz

$\therefore$ Error = ... Hz = ... %

Precautions :

1. The sonometer wire should be uniform and free from kinks.

2. For bringing the wire in unison with the tuning fork, start with a small length of the wire and alter the length in small increments.

3. Unison should always be tested by the method of removal of beats.

4. While finding out the tension of the wire, do not forget to add the mass of the hanger.

5. While increasing the tension of the wire, be careful that the wire is not stretched beyond elastic limit. For this purpose, before starting the experiment have an idea of the magnitude of the breaking load of the given wire with the help of Table of Physical constants.

6. The excited tuning fork should be placed vertically with its stem pressed against the top of the sounding box.

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7. The tuning fork should never be struck against a hard surface and when excited should be held in hand with its stem.

8. After completing the experiment remove weights from the hanger. Under no circumstances should the wire be left in a stretched condition.

9. In plucking a string to excite its note, care should be taken to avoid touching the string with the finger nail as this may introduce overtones. The string should be pulled aside between the thumb and the finger.

Sources of Error :

1. In the derivation of the formula $n = \frac{1}{2l}\sqrt{\frac{T}{m}}$ it has been assumed that the wire is perfectly flexible. Hence due to the rigidity of the experimental wire, an error shall creep in the result.

2. If the wire is not uniform or if its composition is variable, then also the result will be erroneous.

3. In this horizontal pattern of the sonometer, there is always present some friction at the pulley ; hence the value of tension is less than that actually applied. This consequently affects the value of the frequency. Moreover the tension on the two sides of the bridges may not be the same.

4. There is always some practical difficulty for the ear (specially when it is untrained) to establish perfect unison in two musical sounds.

ORAL QUESTIONS

Q. 1. *How is sound produced ?*

Ans. Sound is produced due to vibration of a body.

Q. 2. *Can sound travel in vacuum ?*

Ans. Sound cannot travel in vacuum. A material medium is necessary for its propagation.

Q. 3. *What is a wave motion ?*

Ans. Wave motion is the disturbance which travels in a material medium and is due to the repeated and periodic motion of the particles of the medium about their mean position; the motion being handed over from one particle to the next.

Q. 4. *Define S.H. Motion ; Vibration ; Time Period ; Frequency ; Phase ; Phase difference and Amplitude.*

Ans. *Simple Harmonic Motion (S.H.M.)* : A particle is said to be executing S.H.M., if its acceleration is always proportional to its distance from some fixed point in its path and is always directed towards that point.

Vibration. One vibration is the to and fro motion between two consecutive passages of the particle in the same direction.

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Time Period (T). The time taken to complete one vibration is called the time period.

Frequency (*n*). The number of vibrations completed by the vibrating particle in one second is called the frequency.

Phase. The phase of a vibrating particle at any instant is its state as regards its position and direction of motion at that instant. It is measured either in terms of angle that the particle has described or the time that has elapsed (measured as the fraction of time period T), since the particle last passed through its normal position in the positive direction.

Phase difference. Phase difference between two particles indicates the extent by which the two particles are out of step with each other. It, too, is measured by the time (denoted as a fraction of T) by which one particle is ahead of the other.

Amplitude. The maximum distance covered by the vibrating particle on either side of its mean position is called its amplitude (Fig. 22.2).

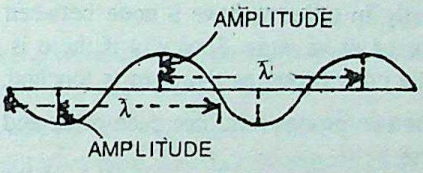

Fig. 22.2

Q. 5. *What are the types of Wave Motion ?*

Ans. (1) Transverse wave motion.

(2) Longitudinal wave motion.

Q. 6. *What is a transverse wave ?*

Ans. It is a wave in which the particles of the medium in which the wave propagates, vibrate along a line which is perpendicular to the direction of propagation of the wave.

Sound travels in the form of transverse waves in strings. Light is a Transverse Wave.

Q. 7. *What is a longitudinal wave ?*

Ans. A wave motion in which the individual particles of the Medium vibrate back and forth along the direction of propagation of the wave is called a longitudinal wave motion.

Q. 8. *Define wave length.*

Ans. It is the distance travelled by the wave during the time the vibrating particle or any other particle of the medium of propagation completes one vibration. It is denoted by the letter λ (Fig. 22.2).

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Q. 9. *Can transverse waves be produced in air ?*

Ans. No, because air does not possess elasticity of shape.

Q. 10. *What types of waves are sound waves ?*

Ans. Sound waves are longitudinal waves.

Q. 11. *What is the relation between frequency and time period ?*

Ans. The reciprocal of time period is called frequency.

$$n = \frac{1}{T}$$

Q. 12. *Why is the tuning fork so-called ?*

Ans. Because it produces a musical sound when struck and has the shape of a fork.

Q. 13. *Why the tuning fork has two prongs ?*

Ans. Firstly in order to have a node between the two anti-nodes which are produced at its ends. Secondly if there is only one prong the vibration will die out as soon as the stem is touched.

Thirdly the two prongs reinforce each other and maintain vibrations for a longer time.

Q. 14. *What are the factors on which frequency of a tuning fork depend ?*

Ans. It depends upon the length, thickness and the material of the prongs.

It is inversely proportional to the square of the length of the prongs. It is directly proportional to the thickness of the prong.

Q. 15. *Of what material the tuning forks are made ?*

Ans. Generally these are made of steel because its elasticity is high and density low. This is because the frequency of a tuning fork is inversely proportional to the square root of the density of the material of the fork and directly proportional to the square root of the elasticity of the material of the fork.

Q. 16. *What is the effect of temperature on the frequency of a fork ?*

Ans. The increase in temperature increases the length of the prongs and thus frequency is decreased.

Q. 17. *How is the effect of temperature minimised ?*

Ans. By making the tuning fork of an alloy called ELINVAR, which is made of steel, nickel and chromium. It has a very low temperature coefficient.

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Q. 18. *Why do we strike the tuning fork on the rubber pad ?*

Ans. To strike it gently so that only fundamental note may be produced.

Q. 19. *What is the effect of loading the prongs with wax ?*

Ans. The frequency of the fork decreases.

Q. 20. *What is the effect of filing the prongs ?*

Ans. The frequency of the fork increases.

Q. 21. *Why do the vibrations of the tuning fork stop after sometime ?*

Ans. Due to frictional force of air.

Q. 22. *What is the relationship between velocity of wave motion, frequency and wave length ?*

Ans. $V = n\lambda$

where V = Velocity of sound, n = frequency and λ = wavelength.

Q. 23. *What type of vibrations are produced in prongs and the stem of the tuning fork ?*

Ans. The free ends of the fork perform transverse vibrations while the longitudinal waves are produced in the stem.

Q. 24. *What happens if we strike the tuning fork with a great force ?*

Ans. It will not give pure note but overtones may be produced.

Q. 25. *Why does the fork remain vibrating even when we hold it by the handle ?*

Ans. Because the handle performs longitudinal vibrations which are not stopped by touching.

Q. 26. *Why does the tuning fork give a pure note only ?*

Ans. Because the first overtone is very weak. It is about six octaves higher than the fundamental note.

Q. 27. *Why does the tuning fork stop vibrating when we touch the prong ?*

Ans. Because the prongs execute transverse vibrations which stop on touching.

Q. 28. *Does the frequency of the tuning fork change with time ?*

Ans. No ; it remains the same. Only the decrease in amplitude decreases the loudness of the sound because the intensity of sound is directly proportional to the square of the amplitude.

Q. 29. *What is the difference between a note and a tone ?*

Ans. A note is a sound of definite frequency produced by a periodic complex vibrations where as a sound produced by a pure sine vibrations is called a tone.

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Q. 30. *What is a fundamental note ?*

Ans. The note produced of lowest frequency is called a fundamental note.

Q. 31. *What are overtones ?*

Ans. The notes of the higher frequencies other than fundamental note are called overtones.

Q. 32. *What is the difference between frequency and pitch ?*

Ans. Frequency is the number of vibrations made per second. Pitch is the physical characteristic of sound depending upon frequency. The greater the frequency, the higher the pitch and *vice versa.*

Q. 33. *Why do the prongs vibrate even though we strike only one ?*

Ans. Energy is transmitted from one prong to another through the material of the fork and thus both begin to vibrate.

Q. 34. *Why is sonometer so called ?*

Ans. Because it enables us to measure the frequency of vibrating body producing sound.

Q. 35. *Why are there holes in the wooden box ?*

Ans. So that internal air and external air may have a direct contact.

Q. 36. *Why is the wooden box hollow ?*

Ans. So that the whole of the air inside the box may begin to resonate thus increasing the intensity of the note.

Q. 37. *What types of waves are produced in the sonometer wire ?*

Ans. Transverse and stationary waves are produced in the wire.

Q. 38. *What types of waves are produced in the surrounding air ?*

Ans. Longitudinal and progressive waves are produced in the surrounding air.

Q. 39. *What type of wire should we use ?*

Ans. The wire should be thin, uniform and flexible.

Q. 40. *What are progressive waves ?*

Ans. The progressive waves are those in which all the particles execute simple harmonic motion and there is a regular phase difference between the particles of the medium.

Q. 41. *What are stationary waves ?*

Ans. When two sets of progressive waves, having the same amplitude and period, but travelling in opposite directions with the same velocity meet each other in a confined space, the result of their superposition is a set of waves, which only expand and shrink but do not proceed in either direction. These waves are called stationary waves.

Q. 42. *Why are they called stationary waves ?*

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Ans. They are so-called because they remain confined in the region in which they are produced and are non-progressive in character.

Q. 43. *What are nodes ?*

Ans. Nodes are those points in the stationary waves where the particles are permanently at rest and strain is maximum.

Q. 44. *What are anti-nodes ?*

Ans. Anti-nodes are those points in the stationary waves where the displacement is maximum and strain is zero.

Q. 45. *What is the distance between two consecutive nodes or anti-nodes ?*

Ans. It is equal to half the wavelength ($\lambda/2$).

Q. 46. *What is the distance between a node and an anti-node ?*

Ans. It is equal to quarter of the wavelength ($\lambda/4$).

Q. 47. *What is the function of knife edges or bridges ?*

Ans. The knife edges (or bridges) reflect the sound and produce stationary waves.

Q. 48. *Is it necessary to keep the wire horizontal ?*

Ans. No, it can be kept vertical also.

Q. 49. *How is the energy communicated from wire to the sound box ?*

Ans. Through the bridges.

Q. 50. *What are the laws of vibration of strings ?*

Ans. The fundamental frequency of a vibrating string is inversely proportional to the length ; directly proportional to the square root of the tension and inversely proportional to the square root of the mass per unit length.

Q. 51. *How is the frequency of the wire affected if the wire is made hollow ?*

Ans. Its frequency increases because mass per unit length decreases.

Q. 52. *What is the function of a V-shaped paper rider ?*

Ans. The paper rider placed at the middle point (anti-node) is thrown off when the resonance is obtained.

Q. 53. *What do you mean by unison ?*

Ans. The two notes are said to be in unison if they have same frequency.

Q. 54. *Why do you start from the minimum length of the wire ?*

Ans. So that the wire vibrates in one segment and we may get the position of the fundamental note.

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Q. 55. *Can we use a rubber wire in a sonometer ?*

Ans. No, since it is not rigid. The vibrations die out quickly.

Q. 56. *Why is the sound so loud when we press the stem of the vibrating tuning fork against the board ?*

Ans. Due to forced vibrations produced in the sounding board which has a large surface area, so greater is the loudness.

Q. 57. *What do you mean by sympathetic vibrations (or Resonant vibrations) and Resonance.*

Ans. Sympathetic (or Resonant) vibrations are those which are produced in a body due to the presence of a neighbouring vibrating body of the same frequency. The phenomenon is called resonance.

Q. 58. *What are beats ?*

Ans. The alternate waxing and waning of sound when the notes of nearly same frequency are sounded together is known as phenomenon of beats.

Q. 59. *What are the limits of audibility ?*

Ans. We can hear sounds between the frequencies varying from 20 to 20,000 cycles per second.

Q. 60. *What will be the nature of the graph between 'n' and 'l' ?*

Ans. Hyperbola.

Q. 61. *What type of graphs will be between (a) n and* $\frac{1}{l}$ *(b)* n^2 *and T (c)* l^2 *and T ?*

Ans. Straight lines.

Q. 62. *What type of graph do you expect between n and T ?*

Ans. A parabola.

Q. 63. *How will the length between the bridges change if*

(a) tension is doubled.

(b) a tunig fork of double the frequency is used.

(c) radius of the wire is doubled.

Ans. (*a*) The length will become $\sqrt{2}$ times the first length.

(*b*) and (*c*). The length will become one-half.

Q. 64. *What are the uses of a sonometer ?*

Ans. A sonometer is used

(*a*) to determine the frequency of a tuning fork.

(*b*) to determine the weight of a given body.

(*c*) to verify the laws of vibrating strings etc.

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Q. 65. *Draw a diagram showing nodes and anti-nodes on a vibrating tuning fork.*

Ans.

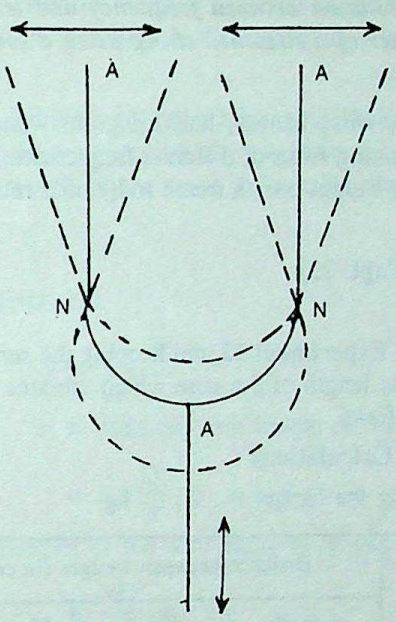

Fig. 22.3

Q. 66. *Will the resonant length change if we have a fork of different frequency but keep the load same ?*

Ans. Yes ; the resonant length will change as the frequency is inversely proportional to the resonant length of the wire keeping tension constant *i.e.*,

$$\boxed{n_1 l_1 = n_2 l_2}$$ provided the load is the same.

Q. 67. *How does the friction at the pulley affect the result ?*

Ans. Due to friction, the value of tension (T) is less than that actually applied. This consequently affects the value of the frequency (n) as $n \propto \sqrt{T}$.

□□

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EXPERIMENT 23

To find the relation between frequency and length for constant tension and diameter of a stretched string using a sonometer.

Apparatus :

A sonometer, wire, hanger, half kilogram weights, two wedges, wooden blocks, 3 tuning forks of different frequencies, a pair of scissors, sensitive balance, a weight box, a metre rod, and a rubber hammer.

Theory :

(Same as in Expt. 22).

Procedure :

Proceed as in **Experiment 22** and keeping the *same tension* and the *same string*, find the length of the wire which vibrates in resonance with each of the tuning forks.

Observations and Calculations :

Load including the hanger = ... kg

S.No.	Frequency (n) Hz	Distance between wedges (in cm)			$n \times l$
		Length increasing	Length decreasing	Mean Length (l)	
1.					
2.					
3.					

Verification : Since $n \times l$ = constant, the law of length is verified *i.e.*,

$$n \propto \frac{1}{l}.$$

Precautions :

(Same as in Expt. 22).

Sources of Error :

(Same as in Expt. 22).

ORAL QUESTIONS

(Same as in Expt. 22).

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EXPERIMENT 24

To study the relation between length and diameter for constant frequency and tension of a stretched string using a sonometer.

Apparatus :

A sonometer, 3 different wires, a hanger, half-kilogram weights, two wedges, wooden blocks, a tuning fork of known frequency, a pair of scissors, sensitive balance, a weight box, a metre rod, a rubber hammer and a screw gauge.

Theory :

(Same as in Expt. 22).

$$n = \frac{1}{2l}\sqrt{\frac{T}{m}}$$

where m = mass per unit length of the wire.

$$= 1.\pi\frac{D^2}{4}.\rho$$

where D = diameter of the wire and ρ = its density.

$$= \frac{\pi D^2}{4}.\rho$$

$$\therefore \quad n = \frac{1}{2l}\sqrt{\frac{T.4}{\pi D^2.\rho}}$$

or $$n = \frac{1}{lD}\sqrt{\frac{T}{\pi\rho}}$$

Since n, T and ρ are constant so

$$lD = \text{constant}$$

or $$l \propto \frac{1}{D}.$$

Procedure :

1. Stretch the wire with a load of 4 kg including the hanger and find the length of the wire which vibrates in resonance with a given tuning fork as explained in Experiment 22.

2. Find the diameter of this wire as explained in Expt. 3 in Section A (using screw gauge).

3. Repeat with the same load and the same tuning fork for three different wires.

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Note : *The wires may be of different materials and different diameters.*

Observations and Calculations :

Load including the hanger = ... kg

Frequency of the tuning fork = n = ... Hz

Wire No.	Length of the wire giving note of frequency n (in cm)			Corrected Diameter of the wire (D) in cm	$l \times D$
	Increasing	Decreasing	Mean (l)		

Diameter of the wire :

Least count of the screw gauge = ... cm

Zero error = ... cm

Zero correction = ... cm

Verification :

Since it has been observed above that $l \times D$ = constant so we find that $l \propto \frac{1}{D}$.

Result :

For the same frequency (n) and tension (T) of a stretched string of a sonometer, the length (l) of the string is *inversely proportional* to its diameter (D).

Precautions :

(Same as in Experiment 22)

Sources of Error :

(Same as in Experiment 22)

ORAL QUESTIONS

(Same as in Experiment 22).

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Wire No.	One direction			Mutually perpendicular direction			Mean Observed diameter $D=\left(\frac{d_1-d_2}{2}\right)$ in mm
	Main scale reading (a) in (mm)	No. of circular division coinciding (n)	Observed diameter in mm $= (a) + n \times$ L.C. (d_1)	Main scale reading (a) in mm	No. of circular division coinciding (n)	Observed diameter in mm $= (a) + n \times$ L.C. (d_2)	
1.							
2.							
3.							

Corrected diameter (D_1) of Wire No. 1 = ... mm
= ..... cm

Corrected diameter (D_2) of Wire No. 2 = ... mm
= ..... cm

Corrected diameter (D_3) of Wire No. 3 = ... mm
= ..... cm

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EXPERIMENT 25

To find the velocity of sound at room temperature using resonance tube and to calculate its value at 0°C.

OR

To determine the wavelength of sound by taking first and second resonance positions using Resonance tube and explain the difference, if any and hence determine velocity of sound at room temperature and to calculate its value at 0°C. Also find the end correction.

Apparatus :

Resonance tube apparatus, Two tuning forks of different frequencies (say 480 vib/sec or hertz and 512 vib/sec ot hertz) or more, Celsius thermometer, A rubber pad, Pair of set squares, A beaker, A plumb line, Water, Vernier callipers.

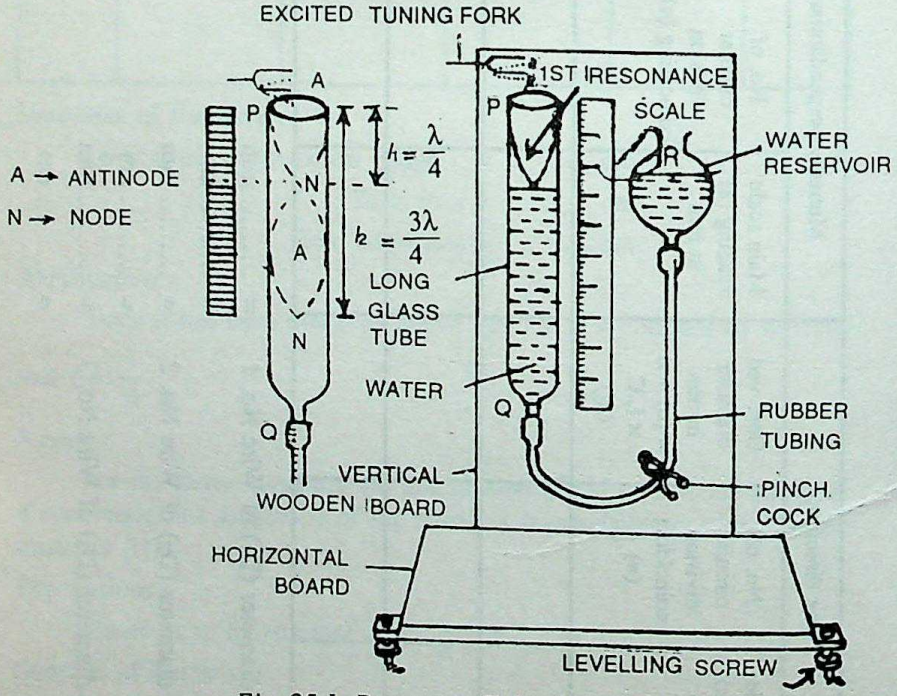

Fig. 25.1. Resonance Tube Apparatus.

Theory :

Resonance is the phenomenon of vibratory motion produced in a body by the influence of the vibrations of another body when their frequencies are exactly the same.

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An air column can easily be set into vibrations with the help of a tuning fork. The frequency of the air column can be adjusted equal to that of the tuning fork by varying its length. This can be easily achieved with the help of an apparatus called **resonance tube** (Fig. 25.1).

The resonance tube apparatus consists of a glass tube PQ about 1 metre long and 5 cm in diameter fixed along a metre scale on a vertical wooden board or stand. The lower end of the tube is connected by a rubber tube to a reservoir (R) which can slide up and down along the scale and can be clamped in any desired position. A part of the tube and reservoir are filled with water. By means of a pinch-cock, the flow of water from the reservoir to the tube and from the tube to the reservoir can be regulated. The base is provided with levelling screws.

Let a tuning fork of frequency 'n' be struck against a rubber pad and held at the open end (P) of the tube as shown in Fig. 25.1. Adjust the level of water in the tube so that the air column begins to vibrate in resonance with the turning fork and **a loud sound is heard.** Let us understand what happens when the **air column resonates.**

When the prong of the tuning fork starts its downward journey from mean position, it sends down in the tube a wave of compression that reaches the level of water at B and is reflected at a denser medium as a wave of compression. If the wave of compression reaches P, when the prong of the tuning fork reaches its mean position the sound becomes very loud and resonance occurs. It is because the tuning fork after reaching its mean position starts its upward journey and sends down in the tube a wave of rarefaction. The previous wave of compression is reflected at P as a wave of rarefaction since the reflection takes place at rarer medium because the air inside the tube being in a state of compression is comparatively denser than the outside air. The two waves of rarefactions thus, superimpose on each other producing **stationary waves** and the amplitude of the air particles increases, thereby resulting in the increase of intensity in loudness. The open end of the tube always acts as an **anti-node**—a point where amplitude is the greatest and the changes of pressure and density are zero and closed end as a **node**—a point where the amplitude is zero but the changes of pressure and density are maximum.

It is clear from above that during the time the prong completes **half a vibration,** the wave travels a distance equal to **twice** the length of the air column. Hence the wave travels four times the length of the air column during the time the prong completes one vibration. Since the distance that a wave travels in one period is equal to one wavelength, therefore, the wavelength—'λ' of the note is four times the length l_1 of the air column

i.e., $\lambda = 4l_1$

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Similarly, it may be argued that for the second resonance position during the time the prong makes three and half vibrations, the wave travels twice the length (l_2) of the air column as shown in Fig. 25.1. If 'l_2' denotes the length, then $\frac{3\lambda}{2} = 2l_2$

or $$\boxed{\frac{3\lambda}{4} = l_2}$$

or $$\boxed{\lambda = \frac{4l_2}{3}} = 4l_1$$

$\therefore$ $$l_2 = 3l_1$$

End correction and velocity of sound at room temperature

It has been, however, shown by Lord Rayleigh that the anti-node is not just at the open end (P) of the tube but slightly above it ; so a small correction is to be applied in the observed length of the air column. This correction is known as **End correction** and is found to be 0·3 D, where D is the **internal diameter** of the resonant tube. Thus for the first resonance :

$$\lambda = 4[l_1 + 0{\cdot}3\ D]$$

and for second resonance position

$$\lambda = \frac{4}{3}[l_2 + 0{\cdot}3\ D]$$

The end correction 'x' can be determined experimentally as follows :

For 1st resonance $$l_1 + x = \frac{\lambda}{4} \qquad \ldots(i)$$

and for second resonance $$l_2 + x = \frac{3\lambda}{4} \qquad \ldots(ii)$$

Multiply (i) by 3 and subtract it from (ii), we have

$$3(l_1 + x) = l_2 + x$$

or $$\boxed{x = \frac{l_2 - 3l_1}{2}}$$

Subtracting (i) from (ii), we have

$$l_2 - l_1 = \lambda/2$$

$\therefore$ $$\lambda = 2(l_2 - l_1)$$

Hence $$V = n\lambda$$

or $$\boxed{V = 2n\ (l_2 - l_1)}$$

where V is the velocity of sound at room temperature.

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Again, $\frac{V_0}{V_t} = \sqrt{\frac{273}{273+t}}$ where t is the temperature in °C ;
V_0 is the velocity of sound at 0°C
and V_t is the velocity of sound at t°C.

Procedure :

1. Set the resonance tube vertical with the help of plumb line and levelling screws so that the vertical board is equidistant from the thread of the plumb line at every point.

2. Pour water in the reservoir (R) and the tube (PQ). Test the pinch-cock *i.e.*, the water level in the tube does not change when the pinch-cock is closed and note down the room temperature in °C.

3. Strike gently a tuning fork of known frequency say 512 hertz on the pad. Hold it above the open end of the tube so that its prongs are horizontal and vibrate in a vertical plane as in Fig. 25.1.

Now adjust the level of water in the resonance tube by raising and lowering the reservoir till you hear a sound of **maximum intensity.** The air column is said to vibrate due to **'resonance'**. Note the position of the water level with the help of a set square on the scale. Note the length of the resonance air column. This position corresponds to the first resonance position.

Lower the water level in the tube further by few cms and then close the pinch-cock and raise the reservoir a few centimetres. Now gently open the pinch-cock so as to allow the water level to rise slowly. Replace the vibrating tuning fork and note the position B of the water level at which the intensity of sound is maximum. Note the length of air column again. The mean of these two readings gives the length l_1. Confirm the resonance position by taking four readings, two when the water level is **falling** and the other two when the water level is **rising.**

4. Lower down the reservoir to the bottom so that the length of air column is approximately, increased three times and proceed in the same way to find the second resonance position. Take the mean of two readings for the second resonance with the water level falling and rising to get 'l_2'. Repeat these observations thrice.

5. Repeat the experiment with another tuning fork of known frequency (say 480 Hz) and find the mean of two values of the velocity of sound in air at room temperature.

6. Measure the internal diameter of the tube with the help of vernier callipers in different positions.

7. Note the room temperature with the help of the thermometer.

Observations and Calculations :

Room temperature at the start of the experiment= t_1 = ... °C
Room temperature at the end of the experiment= t_2 = ... °C

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Frequency of the tuning fork (n) in Hz	S. No.	FIRST RESONANCE			Mean (l_1) in cm	Wavelength $\lambda = 4[l_1 + 0{\cdot}3D]$ (cm)	SECOND RESONANCE			Mean (l_2) in cm	Wavelength $\lambda = \frac{4}{3}[l_2 + 0{\cdot}3D]$ (cm)	Velocity of sound in air at t°C $V_t = 2n(l_2 - l_1)$ (cm/s)	Mean Velocity of sound V_t at t°C (cm/s)
		Position of water level					Position of water level						
		Falling	Rising	Mean			Falling	Rising	Mean				
512	1.												
	2.												
	3.												
480	1.												
	2.												
	3.												

End correction $x = \frac{l_2 - 3l_1}{2}$ = ... cm

By observation $x = 0{\cdot}3\ D$ = ... cm

Velocity of sound at 0°C = $V_0 = V_t\sqrt{\frac{273}{273+t}}$ = ... cms^{-1} where t is the mean room temperature.

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Mean room temperature = t°C = $\frac{t_1 + t_2}{2}$ =.....°C

Vernier constant of vernier callipers = ... cm

Zero correction of the vernier callipers = ... cm

Observed internal diameter of the tube (1) = ... cm

(2) = ... cm

(3) = ... cm

Mean corrected internal diameter (D) of the resonance tube

= ..... cm

Position of the upper end of the tube = ... cm mark

Result :

(*i*) An air column can be easily set into resonant vibrations with the help of a turning fork.

(*ii*) Wave length of the sound wave = ... cm = ... metre

(*iii*) Velocity of sound in air at room temperature

t°C = ... cm/s = ... m/s

(*iv*) Velocity of sound at 0°C = ... cms^{-1} = ... ms^{-1}

(*v*) End correction = ... cm

Precautions :

1. The resonance tube should be vertical.

2. The tuning fork should be gently struck against a soft rubber pad. It should never be banged as this process will in time cause a slight change in frequency.

3. The prongs of the tuning fork should not touch the edge of the tube and their ends should remain in the centre of the tube.

4. The resonance should be obtained for water level rising as well as falling in the tube.

5. The tuning fork should not be roughly handled.

6. Reading of the lower meniscus of the water level should be noted with set squares.

Sources of Error :

(1) The presence of moisture in the tube will raise the velocity of sound.

(2) Position of the resonance especially second resonance cannot be accurately determined.

Note. Before starting the experiment the velocity of sound in cm/s at room temperature is calculated by $V_t = 33200 + 61t$ where t is the room temperature and hence the approximate position of the 1st resonance is determined by $l_1 = \frac{V_t}{4\nu}$ cm. Now the experiment should be started by keeping the water level at this position.

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ORAL QUESTIONS

Q. 1. *Name the various types of vibrations ?*

Ans. There are three types of vibrations :

(*a*) Free (*b*) Force and (*c*) Resonant vibrations.

Q. 2. *What are free vibrations ?*

Ans. When a body vibrates with its natural frequency, without being disturbed by any other external force, it is said to have free vibrations.

Q. 3. *What are forced vibrations ?*

Ans. A body is said to execute forced vibrations if it is made to vibrate with a frequency other than its natural frequency by the application of some external force.

Q. 4. *What are resonant (or sympathetic vibrations) ? What is resonance ?*

Ans. A body is said to execute resonant (or sympathetic) vibrations if it is made to vibrate with its natural frequency by the application of some external force having the same frequency as that of the body. This phenomenon of producing vibratory motion in a body by the influence of some external force (or a second vibrating body) having the same natural frequency as the first is called **resonance.**

Q. 5. *What is resonance column ?*

Ans. It is the air column between the surface of water and the tuning fork.

Q. 6. *What is the function of water in the resonance tube apparatus ?*

Ans. Water acts as a denser medium and reflects the longitudinal waves produced in air due to vibration of prongs of tuning fork.

Q. 7. *Can we use any other liquid ? Why water ?*

Ans. Yes ; any liquid can be used. Water is used because it is cheapest of all.

Q. 8. *What types of waves are produced in the tube ?*

Ans. Stationary Waves (or Standing Waves)

Q. 9. *Is there node or anti-node (i) at the upper end of the tube, (ii) at the surface of water ?*

Ans. There is an anti-node at the upper end of the tube and a node at the surface of water ?

Q. 10. *When does resonance occur ?*

Ans. When the frequency of vibrating air column becomes equal to

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that of the tuning fork and thus maximum sound is produced due to resonance.

Q. 11. *What is the use of pinch-cock ?*

Ans. It is used for adjusting the level of water in the resonance tube.

Q. 12. *What is End correction ?*

Ans. The reflection of longitudinal waves at the upper end of the resonance tube takes place at a position which is a little higher than the open end. This distance above the upper end is called End-correction. It is numerically equal to 0·3 times the internal diameter of the tube. The error is called End-error.

Q. 13. *Can we take resonance tube of square cross-section ?*

Ans. Yes ; it can have any shape.

Q. 14. *Why do we use a long tube ?*

Ans. So that we may get two resonance positions and thus end correction may be eliminated.

Q. 15. *What is the effect of temperature, density and pressure on the velocity of sound ?*

Ans. The velocity of sound is directly proportional to the square root of absolute temperature ; inversely proportional to the square root of density while pressure has no effect.

Q. 16. *In which medium is the velocity of sound greatest—iron ; water or air ?*

Ans. It is greatest in iron, less in water and least in air.

Q. 17. *Are the waves in the resonance column and sonometer of the same nature ?*

Ans. No ; the waves in resonance column are longitudinal while in sonometer there are transverse waves.

Q. 18. *Are the waves in resonance column and sonometer progressive or stationary ?*

Ans. The waves in both the cases are stationary.

Q. 19. *How should the tuning fork be placed over the resonance tube.*

Ans. The tuning fork be placed just above the open end with its length perpendicular to the length of the air column.

Q. 20. *Why do you take two positions of resonance in the tube ?*

Ans. To eliminate End-correction.

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Q. 21. *Why is the first resonance produced at a distance of $\lambda/4$ and not at $\lambda/2$?*

Ans. Under the condition of first resonance, the resonating length of the tube is travelled twice by the compression and twice by the rarefaction corresponding to one wavelength (λ). Therefore the resonating length of the tube is one quarter ($\lambda/4$) of a wavelength. Moreover this resonating length is the shortest length of the resonance column of air, with an antinode at the open end and a node at the water surface.

Q. 22. *Why do you get the second position at approx. three times the first resonant length ?*

Ans. In the second position at resonance, the fork completes three vibrations in the time the sound travels four times (two times compression and two times rarefaction) the length of the tube. Therefore, in this case the length of the air column is equal to three quarters of the wavelength *i.e.*, approximately three times the first resonant length.

Q. 23. *Why is the second resonance feebler than the first ?*

Ans. At the second resonance, the vibration in the air column corresponds to the first overtone which is very weak.

□□

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EXPERIMENT 26

To compare the frequencies of two tuning forks using the resonance tube and find the end correction.

Apparatus :

(Same as in Expt. 25).

Theory :

(Same as in Expt. 25)

Procedure :

1. Proceed as in **Experiment 25** and find the length of first resonance air column (l_1) and the length of second resonance air column (l_2) with tuning fork of frequency n_1.

2. Repeat the experiment with another tuning fork of frequency n_2 and find the length of first resonance air column (l'_1) and length of second resonance air column (l'_2).

3. Enter the observations and calculations in the tabular form as given below (*i.e.*, on the next page).

Verifications :

(*i*) $\frac{n_1}{n_2}$ =..... (The values of n_1 and n_2 are written on the tuning forks)

(*ii*) **End Correction :**

Vernier constant of vernier callipers = ... cm

Zero correction of vernier callipers = ... cm

Observed internal diameter of the tube

(1) ..... cm (2) ..... cm (3) ..... cm

Mean corrected internal diameter (D) of the resonance tube=..... cm

End correction = x = 0·3 D = ... cm

Result :

(*i*) $\frac{n_1}{n_2} = \frac{l'_2 - l'_1}{l_2 - l_1}$ =.....

(*ii*) End correction = ... cm

Precautions :

(Same as in Expt. 25).

Sources of Error :

(Same as in Expt. 25).

ORAL QUESTIONS

(Same as in Expt. 25).

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Observations and Calculations

Tuning fork of frequency	S. No.	FIRST RESONANCE			Mean (l_1) in cm	SECOND RESONANCE			Mean (l_2) in cm	$\frac{n_1}{n_2}=\frac{l_2-l}{l_2-l_1}$	End correction (x) in cm
		Position of water level				Position of water level					
		Falling	Rising	Mean		Falling	Rising	Mean			
n_1	1. 2 3.				l_1 = cm				l_2 = cm		$x=\frac{l_2-3l_1}{2}$
n_2	1. 2. 3.				l'_1=cm				l'_2=cm		$x=\frac{l'_2-3l'_1}{2}$
										Mean =	

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EXPERIMENT 27

To study the rate of the cooling of molten naphthalene/wax and to draw and interpret graph between temperature and time and hence determine the melting point of naphthalene/wax.

OR

To study the relationship between temperature of a body and time as it cools by radiating heat.

Apparatus :

A hard glass test-tube fitted with a cork with two holes ; a stirrer ; half degree celsius thermometer ; naphthalene or wax ; stand ; clamp, tripod stand with wire gauze ; beaker ; a stop watch.

Theory :

If a cooling curve is drawn between time and temperature of a substance heated to a temperature a few degrees above its melting point, then we get a **flat** part of the curve parallel to the time-axis (Fig. 27.2) indicating that although heat was continuously lost by radiation by the substance during this stage, yet its temperature remained almost constant. This will happen during the process of melting as well and the temperature corresponding to this flat part is the **melting point** of the solid.

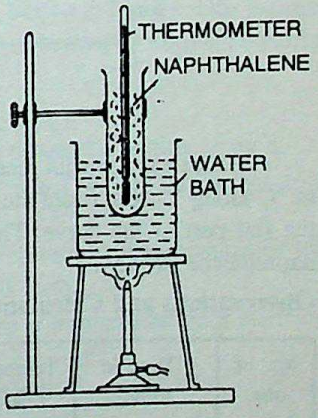

Fig. 27.1

Procedure :

1. Put sufficient quantity of naphthalene or wax in a hard glass test-tube. Place a thermometer, and a stirrer in it and see that the bulb of the thermometer does not touch the walls of the tube.

2. Hold the test-tube in a clamp and suspend it inside a water bath heated by a burner (Fig. 27.1). Place the thermometer and a stirrer in it. Let the whole of the naphthalene or wax melt and the temperature rise about 10 degrees **above** the melting point.

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3. Remove the burner and suspend the test-tube in an empty beaker to avoid draught. Allow the liquid to **cool slowly** by radiation. Stir the liquid well and note the temperature after every half a minute. The temperature begins to fall steadily but when the naphthalene or wax starts solidifying, the temperature will remain constant for some time and will again begin falling, **though less rapidly**. Continue stirring the liquid till it becomes viscous enough when further stirring is not needed. Continue reading temperature until it falls a few degrees below the melting point.

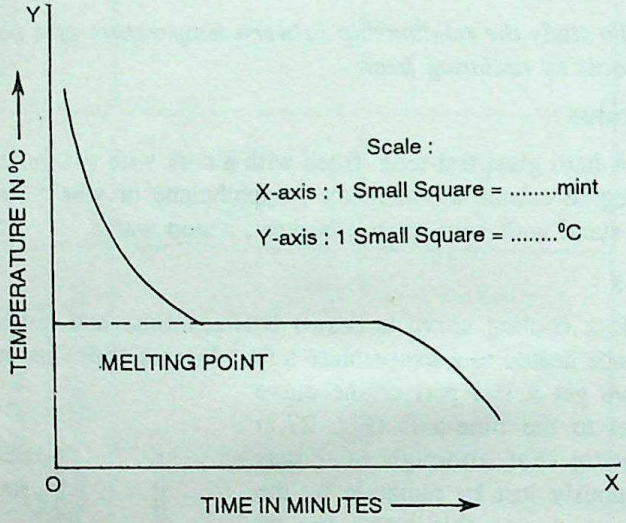

Fig. 27.2. Cooling curve.

4. Plot a graph with time in minutes along X-axis and the temperature in °C along Y-axis. From the graph read the temperature corresponding to the flat part of the curve. This **temperature** is the **melting point** of the naphthalene or wax.

Observations and Calculations

No. of obs.	Time in minute	Temperature in °C	No. of obs.	Time in minute	Temperature in °C
1.			16.		
2.			⋮		
⋮			⋮		
⋮			⋮		
10.			20.		
⋮			⋮		
⋮			⋮		
15.			30.		

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Result :

Melting point of naphthalene or wax as read from the graph = ...°C

Melting point of naphthalene or wax from the melting point table = ...°C

Percentage error = ...%.

Precautions :

1. The bulb of the thermometer should not touch the walls of the tube.
2. Naphthalene should be heated in water bath.
3. Readings should be noted carefully and quickly at regular intervals.
4. Liquid should be allowed to cool slowly.
5. Liquid should be well stirred and stirring should continue till the liquid becomes viscous.

ORAL QUESTIONS

Q. 1. *What is fusion or melting ?*

Ans. When a substance like wax or naphthalene is heated in a vessel, a temperature is reached when the substance begins to liquify. This process of conversion of a solid into its liquid state on heating is known as fusion or melting.

Q. 2. *What is melting point ?*

Ans. It is the temperature at which a substance begins to melt.

Q. 3. *Does the melting point change when the substance converts itself into the liquid form ?*

Ans. No ; the melting point remains constant till the whole of the substance has converted itself into its liquid form.

Q. 4. *What happens to the melting point of a substance if the pressure remains unchanged ?*

Ans. The melting point remains constant.

Q. 5. *What is solidification or freezing ?*

Ans. The change from the liquid to the solid state is known as solidification of freezing.

Q. 6. *What is freezing point ?*

Ans. It is the temperature at which solidification takes place.

Q. 7. *Do the melting points and the freezing points differ in case of pure crystalline substances ?*

Ans. No ; pure crystalline substances solidify at the same temperatures at which they melt.

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Q. 8. *Why can glass be blown into any desirable shape in a pipe flame.*

Ans. This is because glass is a non-crystalline substance and it has no well defined melting point. It passes through a semi-fluid state before changing itself from the solid to the liquid state.

Q. 9. *Can you name more substances which are non-crystalline ?*

Ans. Wrought iron, rubber, etc.

Q. 10. *What happens to the volume of a substance when it melts and when it solidifies ?*

Ans. When a substance changes its state, a change in volume always takes place. In general, the volume on melting increases and on solidification decreases. Gold, silver, copper, paraffin, wax, etc., expand on melting and contract on solidification. But there are some substances, like ice, bismuth, cast iron and antimony which contract on melting and expand on solidification.

Q. 11. *Why does ice float on pure water ?*

Ans. This is because water on freezing expands by about 9% so that 11 cm^3 of water at 0°C shall become 12 cm^3 of ice at the same temperature or 1 cm^3 of water at 0°C shall become 1·09 cm^3 of water after freezing.

Q. 12. *How does the melting point change with the change in the pressure acting upon the body ?*

Ans. The melting point of those substances which expand on melting (*e.g.*, wax, sliver, gold, etc.) is raised by the increase in pressure while the melting point of those bodies which contract on melting *e.g.*, (ice, cast iron, bismuth etc.) is lowered by the increase in pressure.

Q. 13. *Is there a large change in the melting point of a substance due to the change in pressure ?*

Ans. No ; the change in the melting point due to the change in pressure is, however, not large. In the case of ice, the melting point is lowered by 0·0072°C for an increase of pressure equal to one atmosphere, so that under a pressure of 1000 atmospheres, ice would melt at – 7·2°C.

Q. 14. *What is regelation ?*

Ans. The phenomenon according to which ice melts when pressure is increased and again gets solidified when pressure is removed is called regelation.

Q. 15. *What are the Laws of fusion ?*

Ans. (1) Every substance begins to melt at a certain definite temperature depending upon the pressure.

(2) From the time the melting begins the temperature remains constant till the whole substance has melted.

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(3) Unit mass of each substance requires a certain definite amount of heat to melt at the same temperature. This is known as the **latent heat of fusion** of the substance.

(4) Fusion is always accompanied by a change in the volume of a substance. Some substances expand on melting, while others contract on melting.

(5) If a substance expands on melting, its melting point is raised by the increase in pressure and if it contracts on melting, its melting point is lowered by the increase in pressure.

Q. 16. *Why is the temperature constant at the melting ?*

Ans. Melting is the process of breaking the bonds between the molecules of a soild. The latent heat, therefore, represents the energy used in breaking down the force of cohesion which binds together the molecules of a solid. Since heat is being spent in overcoming the force of cohesion, no rise in temperature takes place. In other words, the temperature remains constant during the process of melting.

□□

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ACTIVITIES

Minimum of 7 activities *(a minimum of 3 from each section)* **are to be performed.**

Record of performance of 7 activities is to be maintained. However, activities will not be given for performing in the annual examination.

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SECTION A

(A minimum of 3 from Section A)

ACTIVITY 1

Aim :

To find the least count of the given stop-clock/watch and use it for checking the time period of oscillations of varying amplitude of a simple pendulum of 1 metre length.

Apparatus :

Laboratory stand ; split cork ; fine cotton thread ; a pendulum bob ; stop-watch ; card-board ; pencil ; protractor.

Diagram :

Same as (Fig. 11.1, Expt. 11) Section A on Experiments.

Theory :

Same as in Expt. 11.

[For angles less than 15°, the error introduced by assuming that $\sin \theta \approx \theta$ is only about 1 percent. Therefore for pendulum vibrations in which the amplitude of the motion does not exceed 15°, pendulum motion is a very good approximation to S.H.M.]

Procedure :

1. Tie one end of the thread to pendulum bob. Pass the other end through split cork and clamp it in stand so that the bob hangs a little beyond the edge of the table. Let the point of suspension of pendulum *i.e.*, where it enters the split cork, be less than 20 cm above the table. Keep the length of the pendulum 1 metre, *i.e.*, the distance from the c.g. of the bob to the point of suspension is 1 metre.

2. Make a large protractor on the card-board in units of 10°. Its centre may be at mid-point of the longer side. Right bisector of longer side is marked 0°, and angles upto 90° are marked on its left and right sides. Fix it on the edge of the table by two drawing pins so that its centre is close to the point of suspension of the pendulum, and 0° line coincides with the pendulum at rest.

3. Oscillate the pendulum with a small amplitude (A), say about 1/4th of 10°, in a plane parallel to the card-board. Examine the stop-watch/ clock and find its least count. Also determine its zero error if any. Measure time taken by, say 20 oscillations. Start the watch when the pendulum crosses the vertical line, while moving, say, towards left. Start counting from zero in order to reduce chances of an error in counting. Stop the

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watch at the count 20, when the pendulum again crosses the vertical line moving towards left. Repeat measurement at least thrice and take their mean. Compute the time for one oscillation *i.e.*, the time-period (t).

4. In a similar manner, measure time-period for oscillations with amplitude of 5°, 7·5°, 10°, 12·5°, 15°.

5. Plot a graph between t and A^2 taking independent variable A^2 along X-axis and t along Y-axis.

Because change in t may be quite small, the scale for t should not start from t = 0. It should start with a value close to the value of t for small amplitude and its scale should be highly enlarged. Due to enlarged scale for t, the points plotted may not lie on the graph and one or two may be rather widely away from it. Draw a straight line as close to all points as possible.

Observations and Calculations :

*Effective length of the simple pendulum = 1 m = 100 cm

Least count of stop-watch/clock = ... s

Zero error of stop-watch/clock = ... s

S. No.	Amplitude (A)	Corrected time for 20 oscillations in s				Time Period $t = \frac{T}{20}$ in sec	A^2
		1	2	3	Mean (T)		
1.							
2.							
3.							
4.							
5.							
6.							

Result :

(*i*) Least count of stop-watch/clock = ... *s*

(*ii*) The graph between t and A^2 is a straight line. This means that the time-period of the pendulum remains the same although the amplitude goes on varying. In other words the time period of a simple pendulum is **independent of amplitude.**

*See Expt. 11 for the effective length of the simple pendulum.

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Precautions and Sources of Error

Same as in Expt. 11.

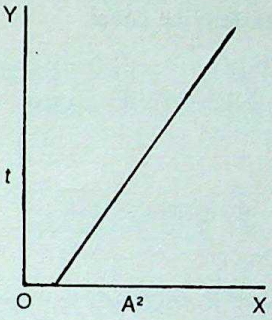

Fig. A-1.1

ACTIVITY 2

Aim :

To find the force of dynamic (sliding) friction for a wooden block on a horizontal plane.

[See Experiment 9 (*a*)]

ACTIVITY 3

Aim :

To find the force of rolling friction for a wooden block moving on rollers on a horizontal plane.

[Same as Experiment 9 (*b*)].

ACTIVITY 4

Aim :

To study the conservation of energy of a ball rolling down an inclined plane (using a double inclined track).

Apparatus :

Double inclined track, steel ball of about 2·5 cm diameter, two wooden blocks each about 2 cm high ; two weights of 1 kg each ; spirit level.

Theory :

Same as in Investigatory Project 5 on page 221.

Procedure :

1. First adjust the table horizontal.

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2. Keep the double inclined track on the table and press its central wings with the help of 1 kg weights Fig. (A-4.1). Insert the wooden blocks under the ends of each track such that both are inclined. The angle of inclination need not necessarily be equal.

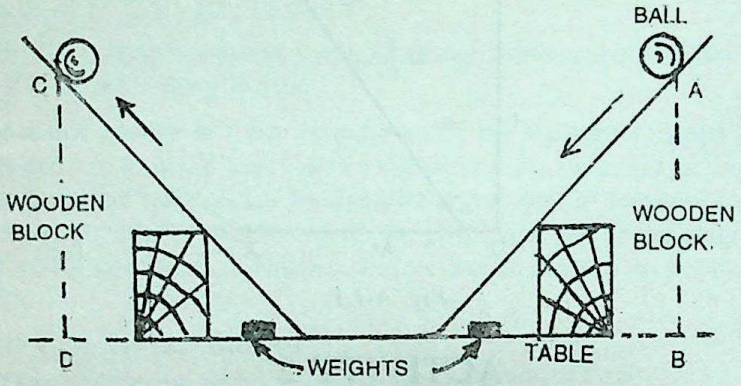

Fig. A-4.1

[You can also use flexible curtain rail as shown in Fig. (P-8.2)—Investigatory Project 8 page 233, as an alternative set up for this experiment].

3. Release the ball from any point, A, say 50 cm mark on the right track. Notice the mark *c* upto which the ball reaches on the left track. Find the vertical height AB of the 50 cm mark from the table. Also find the vertical height CD, the height to which the ball reaches on the left track.

4. Repeat the experiment for various positions of starting point of the ball.

Observations and Calculations :

S.No.	Starting Point A on the right track	Reach of the ball on the left track C	Vertical height of A above table = AB (in cm)	Vertical height of C above tble = CD (in cm)	Difference AB–CD
1.					
2.					
3.					
4.					
5.					

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Result :

Since AB ≈ CD within experimental errors so the energy of the ball rolling down an inclined plane is always conserved. Energy is being transformed from P.E. to K.E. and *vice-versa* with exact equivalence.

Precautions :

Same as in investigatory project 5 on page 221.

ORAL QUESTIONS

(Same as in Expt. 11)

ACTIVITY 5

Aim :

To study the variation in the range of a jet of water by varying the angle of projection.

Apparatus :

Rubber or PVC pipe, a nozzle to obtain jet of water, arrangement for water under pressure from the tap or tank ; a measuring tape and a protractor.

Note. A good venue for this experiment is the garden at your school or home where the source of tap water and hose-pipe are available and you can throw a jet of water to various distances.

Theory :

A projectile may be defined as a body which after having been given an initial velocity is allowed to move under the action of gravity alone. Imagine a body projected upward with an initial speed V_0 at an angle θ to the horizontal (Fig. A-5·1). Its path is a **parabola**. At the instant t, the x-coordinate is the horizontal range R. The maximum horizontal range is realized when $\theta = 45°$.

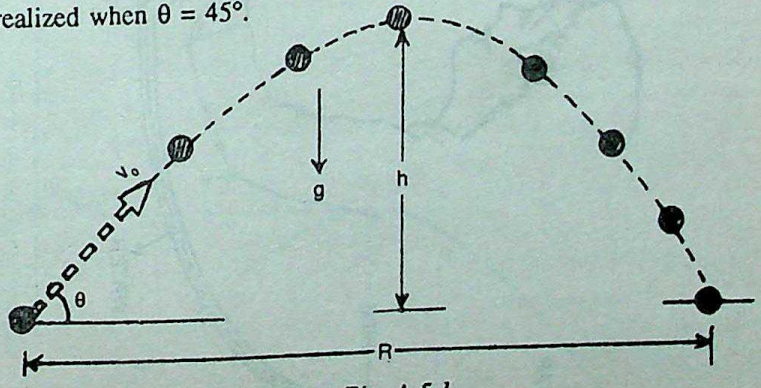

Fig. A-5.1

Procedure :

1. Fix one end of pipe to a tap. At the other end of the pipe, fix the nozzle and obtain jet of water.

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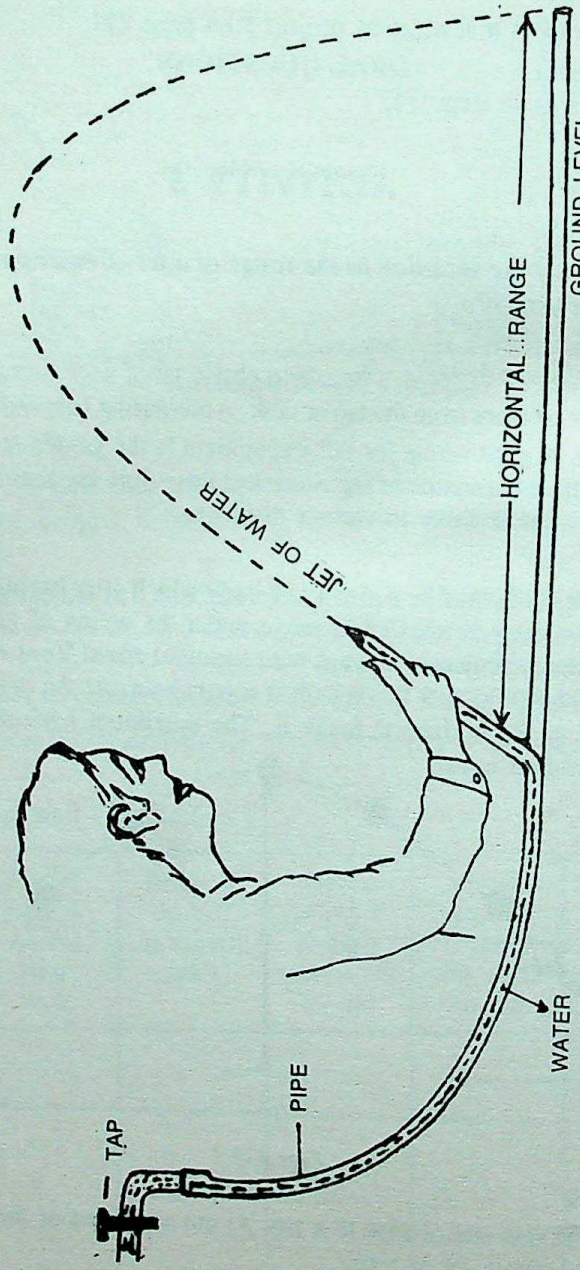

Fig. A-5.2

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2. Put the pipe flat on the ground. Now raise the front portion of the pipe slightly so that the water projects at an angle say 15° to the ground. Notice the range of the jet of water (Fig. A-5.2).

3. Now increase the angle of projection of water by 15°. Note the range of water jet.

4. Repeat the experiment for four more inclinations—increasing each time by 15°.

5. Plot the variation of range with the angle of inclination of pipe.

Observations and Calculations :

Least count of the measuring tape = ...

S.No.	Angle of pipe with the ground (θ) in degrees	Range of water jet (R) in metre
1.	15	
2.	30	
3.	45	
4.	60	
5.	70	
6.	80	

The graph of angle of inclination (θ) of the pipe against the range of water jet (R) is of the type as shown in Fig. A-5.3.

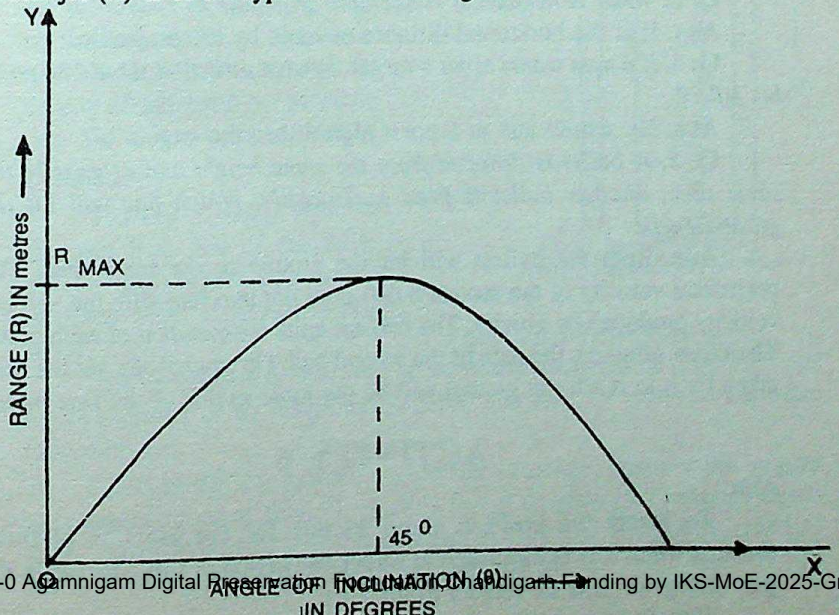

Fig. A-5.3

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Result :

The horizontal range of water jet increases with the increase in angle of inclination of the pipe with the ground, becomes **maximum** when the angle of inclination of the pipe with the ground is 45° and then starts decreasing as the angle of inclination of the pipe increases beyond 45°. The horizontal range is maximum when $\theta = 45°$.

The maximum horizontal Range (R_{max}) = ...m

Precautions :

1. Water under pressure is necessary to obtain a jet of water through a nozzle.

2. First put the pipe flat on the ground and then raise the front portion of the pipe to get the desired angle of inclination of the pipe with the ground.

ORAL QUESTIONS

Q. 1. *What is a projectile ?*

Ans. A projectile may be defined as a body which after having been given an initial velocity is allowed to move under the action of gravity alone *i.e.*, it is no longer being propelled by any fuel *e.g.*, a javelin throw by an athlete, a bomb released from an aeroplane, a bullet shot from a rifle, etc.

Q. 2. *Name the path followed by a projectile.*

Ans. A parabola.

Q. 3. *What is horizontal range of a projectile ?*

Ans. It is the horizontal distance covered by the projectile.

Q. 4. *If a man wants to hit a target, in what direction should he point his rifle ?*

Ans. He should aim at a point *higher* than the target.

Q. 5. *A bullet is dropped from the same height and at exactly the same time, another bullet is fired horizontally. Which one will hit the ground earlier ?*

Ans. Both the bullets will hit the ground *at the same time*. The horizontal velocity of the second bullet does not interfere with the vertical velocity produced by gravity. The two are quite *independent* of each other. Therefore, although the path of the second bullet is a *parabola*, yet the time taken by it to reach the ground will be the *same* as that of the first bullet.

ACTIVITY 6

Aim :

To locate the position of no friction for the junction of three threads when it is in equilibrium under the action of three forces in the parallelogram law of vectors apparatus.

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[See Experiment 6 (*a*)]

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SECTION B

(A minimum of 3 from Section B)

ACTIVITY 1

Aim :

To measure the air pressure inside a balloon using an open ended water manometer/multipurpose mercury barometer.

Apparatus :

A rubber balloon and an open-ended water manometer.

Theory :

A barometer measures atmospheric pressure, but in science we often need to measure pressures other than that of the atmosphere. Instruments used to measure these are known as **pressure gauges** or **manometers.**

A water manometer consists of U-tube containing coloured water [Fig. B-1.1].

When we blow a balloon, it inflates in all directions. This shows that air inside it exerts pressure on all the sides.

The pressure of air inside the balloon is more than the atmospheric pressure by an amount equal to $h\rho g$ where h is the difference in levels of water in the two limbs of the water manometer (Fig. B-1.1) ; ρ is the density of water and g is acceleration due to gravity at a place.

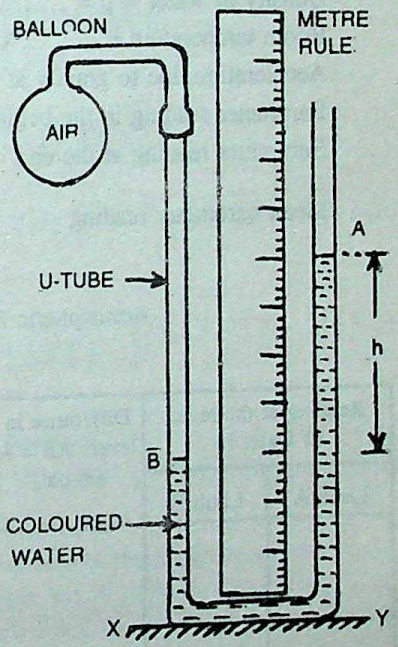

Fig. B-1.1. Water Manometer.

Procedure :

1. Blow a rubber balloon. Connect it to one of the limbs of the manometer containing coloured water as shown in Fig. B-1.1.

The water level in this limb of the manometer will be depressed due to the pressure of air inside the balloon. The level of water in the other limb will rise.

2. When the water in the manometer is steady, measure the heights of water meniscus at A and B above a flat glass plate (XY) placed on the table. The difference in levels, h, of water in the two limbs is measured *i.e.*, AB = h. (AB = h is also called "**head of water**")

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3. The pressure of air in the balloon is, then, more than the atmospheric pressure by an amount equal to $h\rho g$ where ρ is the density of water and g is acceleration due to gravity.

4. Find the atmospheric pressure P at a place using Fortin's barometer as explained in Experiment 13 (Section B on Experiments).

5. The pressure of air inside the balloon is equal to $P + h\rho g$.

Note. Sometimes the pressure of air inside a balloon can be as much as 1·5 m of water column. Thus a huge open-ended manometer should be made using about 3·0 m length of a transparent plastic tube. Alternatively, the multipurpose mercury barometer can be used as an open-ended manometer.

Observations and Calculations :

Density of water = ρ = ... $g\ cm^{-3}$

Room temperature = ...°C

Acceleration due to gravity at a place = g = ... $cm\ s^{-2}$

Barometer reading in the beginning = P_1 = ... cm of Hg

Barometer reading at the end = P_2 = ... cm of Hg

Mean barometer reading = $P = \frac{P_1 + P_2}{2}$

= ..... cm of Hg

$\therefore$ Atmospheric Pressure = P = ... cm of Hg

= ..... $dyne/cm^2$

Reading at the level of water in		Difference in levels AB = h (in cm)	$h\rho g$ ($dyne/cm^2$)	Pressure of air inside the balloon = $P + h\rho g$ ($dyne/cm^2$)
Limb A	Limb B			

Result :

The pressure of air inside a balloon = ... $dyne/cm^2$

= ..... N/m^2

Precautions :

1. The apparatus should be vertical.

2. The water should not stick to the sides of the limbs.

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3. The lower meniscus of water should be read keeping the eye in level with it.

4. Readings should be taken with the help of the set squares.

5. Readings of the atmospheric pressure should be taken before and after the experiment.

6. The mass of air in the balloon should not be changed during the experiment.

Sources of Error :

1. The air in the balloon may not be dry.

2. The barometer height may change during the experiment.

3. The water droplets may remain sticking to the limbs of the manometer during the experiment.

ORAL QUESTIONS

[Same as in Experiment No. 13]

ACTIVITY 2

Aim :

To find the atmospheric pressure using Fortin's barometer and to calculate its value in S.I. Unit.

[See Experiment No. 13]

ACTIVITY 3

Aim :

To study the bending of a bimetallic strip on heating (as well as cooling) and find out which of the two metals has larger linear expansion.

Apparatus :

A strip of copper and a strip of iron of the *same dimensions* **rivetted** (or *welded*) together to form a single bar (**bimetallic strip**) attached to a wooden handle ; a gas burner or a spirit lamp (Heating arrangement) ; Mixture of ice and salt (cooling arrangement).

Theory :

A bimetallic strip consists of two thin strips of different metals connected together. The linear expansion upon the *same increase in temperature* occurs differently for different metals (or materials). Bimetallic strip (or compound bar) is a very important application of **differential expansion.** As the temperature increases, the bimetallic strip bends more and more since this is the only way the two metals can expand without cracking the present (or rivetting) holding them together.

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The bimetallic strip is widely used as a **thermostat**, a device which keeps the temperature approximately constant.

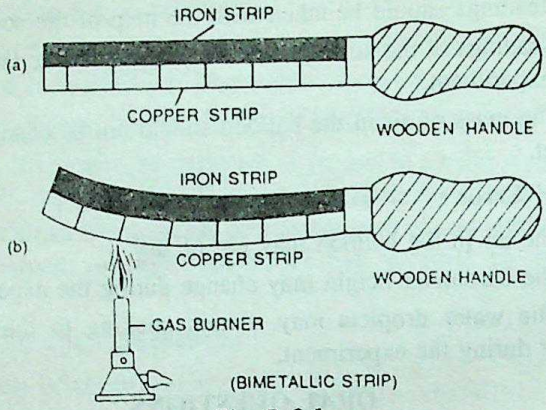

Fig. B-3.1

Procedure :

1. Take a strip (or plate) of copper and a strip of iron of the same dimensions and rivet them together at several points so as to form a single bar or bimetallic strip. Attach this bimetallic strip to a wooden handle [Fig. B-3.1(*a*)].

[**Note.** The rivet itself is a useful example of expansion. When hot, it is pushed through a hole in the metal strips, and is flattened at the top and bottom. When it cools it contracts and holds the two plates firmly together.]

2. Heat the bimetallic strip [Fig. B-3.1 (*b*)] and observe what happens to it.

3. Place the bimetallic strip in a mixture of ice and salt in order to cool it and observe what happens to it.

Inference :

When the bimetallic strip is heated, it bends with the metal *with the larger expansivity on the outside* of the *curve*. In Fig. [B-1.3 (*b*)] copper is on the outside. When the temperature rises the copper strip becomes longer than the iron strip and since it cannot slide over the iron strip, the bimetallic strip *curves to form an arc of a circle.*

When the bimetallic strip is cooled, it tends to bend in the *opposite direction with the copper on the inside* because the metal (copper in this case) that expands more also shrinks more.

Thus, it is clear from this activity that

(*i*) **Copper expands to a larger extent than iron** in the bimetallic strip used in this activity, and

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(*ii*) Internal stresses appear in the bimetallic strip, when its temperature changes on being heated.

ACTIVITY 4

Aim :

To study the real and apparent expansions of liquids.

Apparatus :

A glass flask closed with a rubber plug into which a narrow glass tube is inserted ; a graph paper ; a large glass beaker ; heating arrangement ; thermometer (1/2°C) ; two different liquids (say water and kerosene).

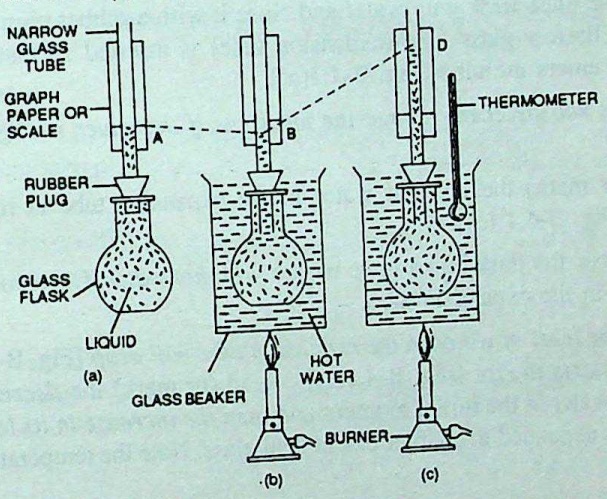

Fig. B-4.1

Theory :

Real and apparent expansion of a liquid : It is senseless to speak about the linear expansion of a liquid since liquids do not have a definite shape and they can flow.

If a glass flask containing liquid is placed into a bowl (or larger glass beaker) of hot water, the level of the liquid first falls and then rises. Why does the level fall ? The glass, which is a bad conductor, gets hot and expands before the heat reaches the liquid. Thus the volume of the glass flask increases and the level of the liquid falls [Fig. B-4.1(*b*)]. However, when the liquid eventually acquires the temperature of its surroundings it expands more than the glass, and its level then rises. Liquids have larger volume expansivities than solids.

Since a liquid has to have a containing vessel, the cubical expansion of the vessel normally has to be taken into account and it is only the **apparent expansion** (*i.e.*, which appears to be) **of the liquid** which is

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noted. Therefore, the **real expansion of the liquid** *is equal to the apparent expansion of the liquid* **plus** *the volume expansion of the containing vessel.*

Thus, in dealing with the expansion of liquids, we have to deal with two kinds of expansion : **apparent** and **real** and consequently there will be two coefficients of expansion.

Coefficient of apparent expansion. *It is the apparent increase in unit volume of a liquid at 0°C, when its temperature is raised by 1°C.*

Coefficient of real expansion. *It is the real increase in unit volume of a liquid at 0°C, when its temperature is raised by 1°C.*

Procedure :

1. Fill the glass flask with water and close it with a rubber plug into which a long narrow glass tube (expansion tube) is inserted so that the liquid (water) enters the tube [Fig. B-4.1(*a*)].

[**Note.** *It will be easier to see the meniscus if the water is slightly coloured.*]

Read (or mark) the level of water in the expansion tube at room temperature [Fig. B-4.1 (*a*)].

2. Immerse the flask into a large beaker with *hot water*. Observe the level of water in the expansion tube.

At first the level of water in the expansion tube will drop [Fig. B-4.1 (*b*)] *and then starts to rise* [Fig. B-4.1(*c*)]. Read (or mark) the *decrease* in the level of water at the initial moment and *then the increase in its level* when water has expanded to a larger extent than glass. Note the temperature of hot water.

The decrease in the level of water at the initial moment indicates that at first the flask expands, while the liquid (water) has no time to be heated throughout. Later the liquid (water) is heated also. The increase in its level indicates that the liquid (water) expands to a larger extent than glass.

Let A be the level of water in the graduated expansion tube at room temperature. Let B be the level of water in the graduated expansion tube when at first the flask expands and there is *decrease* in level of water when the flask containing water is put in a hot bath at *t*°C. Let D be the level of water in the graduated expansion tube when water expands and its level rises. Thus note as follows :

AD = Apparent expansion of water

BD = Real expansion of water

AB = Expansion of flask

3. Repeat the experiment with kerosene oil and note its apparent expansion (AD) and real expansion (BD).

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Inference :

1. *Different liquids expand upon heating to* **different extents.** For example, kerosene expands to a larger extent than water.

2. Liquids have two kinds of expansion : *apparent* and *real.*

ACTIVITY 5

Aim :

To study the co-efficients of apparent expansion of different liquids.

Apparatus :

Specific gravity bottle ; a glass beaker ; heating arrangement ; 1/2°C thermometer ; two different liquids (say turpentine oil and glycerine) ; a hot air blower (or some other drying arrangement) ; Physical balance and weight box.

Theory :

The coefficient of **apparent expansion** of a liquid is defined as the apparent increase in volume per unit volume at 0°C for one degree rise in temperature.

The coefficient of apparent expansion (γ_a) is calculated with the help of the formula.

$$\gamma_a = \frac{m}{M.\theta}$$

where m = mass of liquid expelled when the sp. gravity bottle is placed in a hot bath.

M = Mass of liquid **remaining** in the specific gravity bottle.

θ = Rise in temperature of the liquid.

Let us assume that a specific gravity bottle is filled with a liquid at room temperature θ_1°C. Then it is placed in a bath at a higher temperature θ_2°C, when on account of expansion, some of the liquid overflows. Let the mass of this expelled liquid be m and let the mass of the liquid remaining in the specific gravity bottle be M. Hence the mass of the liquid required to fill the sp. gr. bottle at θ_1°C is $(M + m)$. If the density of the liquid at θ_1°C be ρ then

$$\text{Volume of the sp. gr. bottle} = \frac{(M+m)}{\rho} \qquad \ldots(1)$$

But the mass M of the liquid, whose volume at θ_1°C is M/ρ fills completely the sp. gr. bottle at θ_2°C when the volume is $\frac{(M+m)}{\rho}$.

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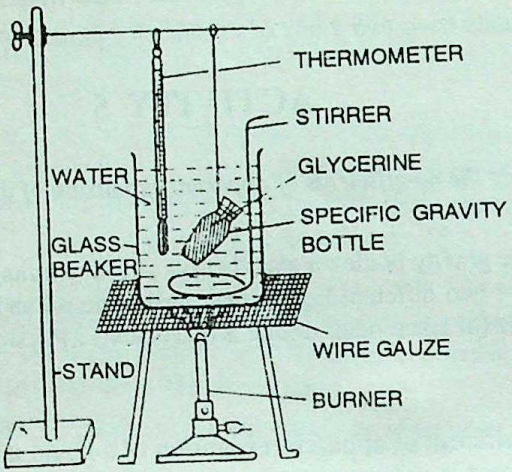

Fig. B-5.1.

Since we are finding the apparent expansion of the liquid, the increase in volume of the glass is neglected. Hence the apparent expansion of the liquid between θ_1°C and θ_2°C.

$$= \frac{(M+m)}{\rho} - \frac{M}{\rho} = \frac{m}{\rho} \qquad \ldots(2)$$

Thus, by definition, the coefficient of apparent expansion of the liquid is given by

$$\gamma_a = \frac{\frac{m}{\rho}}{\frac{M}{\rho} \times (\theta_2 - \theta_1)} = \frac{m}{M(\theta_2 - \theta_1)}$$

or $$\gamma_a = \frac{m}{M(\theta_2 - \theta_1)} \qquad \ldots(3)$$

or $$\boxed{\gamma_a = \frac{\text{mass of the liquid expelled}}{\text{mass of liquid left} \times \text{rise in temperature}}}$$

Procedure :

1. Take a specific gravity bottle and clean it with some alkaline solution and then with dilute acidic solution. Wash it with tap water and dry it with the help of a hot air blower.

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2. Weigh the clean dry specific gravity bottle in a physical balance.

3. Fill the sp. gr. bottle completely with the **slightly warm** liquid (say glycerine) and insert the stopper gently. **See that there is no air bubble** in the sp. gr. bottle.

4. Let the sp. gr. bottle cool and attain room temperature. Clean the bottle cautiously with a piece of filter paper from outside so that any liquid sticking to it is wiped out. Weigh the bottle with the liquid accurately and thus determine the mass of the liquid contained in the bottle at room temperature.

5. Suspend the bottle in a water bath such that its neck remains outside the water level. Suspend a thermometer also from the same stand and note the initial temperature (θ_1) of the water in the bath.

6. Start heating the water bath and keep on stirring the water. As the temperature increases, liquid as a result of expansion oozes out of the stopper of the sp. gr. bottle. Continue heating till the water begins to boil and temperature recorded by the thermometer attains a constant value. When the expulsion of the liquid is over for some time, note the final temperature (θ_2).

7. Take out the sp. gr. bottle, wipe out the water sticking to it and allow it to cool to the room temperature. Again weigh it in the physical balance. This gives us the mass of the liquid remaining in the bulb.

8. From the two weighings calculate the mass of the liquid expelled. Knowing the rise in temperature, mass of the liquid remaining in the sp. gr. bottle and mass of the liquid expelled out, we can calculate the value of the coefficient of apparent expansion for the liquid (glycerine).

9. **The above experiment can be performed with any other liquid (say turpentine oil) exactly in the same way and its γ_a can also be determined.**

So this way we can compare the co-efficient of apparent expansion of a number of liquids.

Note. If water, instead of glycerine, is employed as the experimental liquid, the bath should preferably be maintained at say 60°C. This will minimise the evaporation of water filling the sp. gr. bottle.

Observations :

Mass of empty sp. gr. bottle = m_1 = ... g

Mass of sp. gr. bottle + liquid at initial temperature

θ_1°C = m_2 = ... g

Mass of sp. gr. bottle + liquid (left) at final temperature

(θ_2°C) = m_3 = ... g

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Initial temperature of the liquid = θ_1°C = ... °C

Final temperature of the liquid = θ_2°C = ...°C

Calculations :

Mass of the liquid expelled (m) = ($m_2 - m_3$) = ... g

Mass of the liquid left = M = ($m_3 - m_1$) = ... g

Rise in temperature ($\theta_2 - \theta_1$) = ...°C

$\therefore$ Coefficient of apparent expansion of the liquid

$$= \gamma_a = \frac{m}{M \times (\theta_2 - \theta_1)}$$

$$= \frac{(m_2 - m_3)}{(m_3 - m_1) \times (\theta_2 - \theta_1)}$$

= ..... per °C.

Result :

The coefficient of apparent expansion of glycerine = .../°C

The coefficient of apparent expansion of turpentine oil = .../°C.

etc., etc.

Precautions :

1. The specific gravity bottle should be properly dried before filling it with the given liquid.

2. The specific gravity bottle should not be weighed while it is hot. It should be weighed only when it is cooled to the room temperature. Weighing should be done after wiping off all liquid on the outside surface of the sp. gr. bottle.

3. The sp. gr. bottle should be suspended in water in such a way that only its neck projects outside the water.

4. In these determinations the mass of the expelled liquid is a small quantity. It should, therefore, be determined accurately. Hence all weighings should be done very accurately.

5. The most important precaution in this experiment is that there should be **no air bubble**, however small, anywhere in the sp. gr. bottle.

6. Stir the water continuously and note the temperature accurately.

Sources of Error

(*i*) The neck of the sp. gr. bottle projects outside the water bath. Hence it does not acquire the temperature of the bath, which introduces some error in the result.

(*ii*) The liquid filled in the bottle may not be air free.

(*iii*) Weights used for weighing may not be standard weights.

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ORAL QUESTIONS

Q. 1. *Do liquids have more than one expansion ?*

Ans. Yes ; liquids have **real** expansion in addition to **apparent** expansion.

Q. 2. *Why should a liquid have two expansions ?*

Ans. A liquid is always contained in a vessel and when it is heated, the heat is first taken by the vessel which consequently expands and the level of the liquid falls. Thereafter the heat reaches the liquid which then expands. Hence if we do not take into account the expansion of the container, we shall be finding the *apparent* expansion of the liquid. If we consider the expansion of the container as well, we shall find the real expansion.

Q. 3. *How are the two expansions related ?*

Ans. Real Expansion = Apparent Expansion + Expansion of the vessel.

Q. 4. *A gas is also contained in a vessel, so I think a gas should also have a real and an apparent expansion. Is it not ?*

Ans. Theoretically, it should have. But practically the expansion of a gas is considerably greater than that of the vessel hence the expansion of the latter can be easily neglected without introducing any error.

Q. 5. *Can you give me the order of expansion of glass and air.*

Ans. The coefficient of cubical expansion of glass is 25×10^{-6}, while that for air its value is 36×10^{-4}.

Q. 6. *Why should we try to remove an air bubble specially when it is very tiny bubble ?*

Ans. An air bubble creates an error of appreciable magnitude when the liquid is subjected to heating. Air being highly expansible, the tiny bubble assumes an appreciable Volume and when it goes out of the sp. gr. bottle, it drives along with itself an appreciable amount of liquid. This gives rise to an unnecessarily large expansion.

Q. 7. *Is there any effect of dissolved impurities on the expansion of liquid ?*

Ans. Yes ; the value of coefficient of expansion increases.

Q. 8. *Do all liquids expand when heated or is there any exception ?*

Ans. Yes. There is one exception. Water below 4°C, when heated, *contracts* instead of expanding.

Q. 9. *Define coefficient of apparent expansion of a liquid.*

Ans. The coefficient of apparent expansion of a liquid is the apparent increase in volume per unit volume at 0°C for one degree rise in temperature.

Q. 10. *Define coefficient of real expansion of a liquid.*

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Ans. Coefficient of real expansion of a liquid is the real increase in volume per unit volume at 0°C for one degree rise in temperature.

Q. 11. *What is the relation between the coefficients of real and apparent expansion of a liquid ?*

Ans. Coefficient of real expansion of a liquid (γ_r)

= Coefficient of apparent expansion of a liquid (γ_a)
+ Coefficient of cubical expansion of the vessel (γ_g)

Q. 12. *What is the unit for coefficient of apparent expansion ?*

Ans. Per degree centigrade *i.e.*, /°C.

ACTIVITY 6

Aim :

To determine the spring constant of a given spring.

[See Experiment No. 20—Section B]

ACTIVITY 7

Aim :

To study the variation in length of a rubber band with applied force (beyond elastic limit).

Apparatus :

Rigid support, Peg or nail, Thick rubber string, Pan, Slotted weights of 50 g each, a fine pointer, vertical scale in mm.

Theory :

If a rubber string of length 'L' has a load of 'Mg' suspended from its lower end, then a force equal to Mg dynes acts vertically along the axis of the string and consequently the rubber string extends in length. Let this extension be 'l' cm. Then the longitudinal strain produced in the rubber string is l/L. If the area of cross-section of the rubber string be 'A', then the normal stress set up in the string in the equilibrium state is given by $\frac{Mg}{A}$. The Young's Modulus (Y) for the rubber string is given by

$$Y = \frac{\text{Longitudinal stress}}{\text{Longitudinal strain}} = \frac{\frac{Mg}{A}}{l/L} = \frac{Mg.L}{Al}$$

If the radius of the rubber string be 'r' then $A = \pi r^2$.

Hence $$\boxed{Y = \frac{Mg.L}{\pi r^2.l}}$$

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Procedure :

1. Set up the apparatus as shown in Fig. B-7.1 *i.e.*, suspend a sufficiently thick rubber string from a peg fixed in a rigid support on the wall of the Physics Laboratory. Also suspend the hanger of the slotted weights to the other end of the rubber string. Attach a fine pointer near the lower end of the rubber string which moves over a vertical scale. See that the tip of the pointer is on the scale.

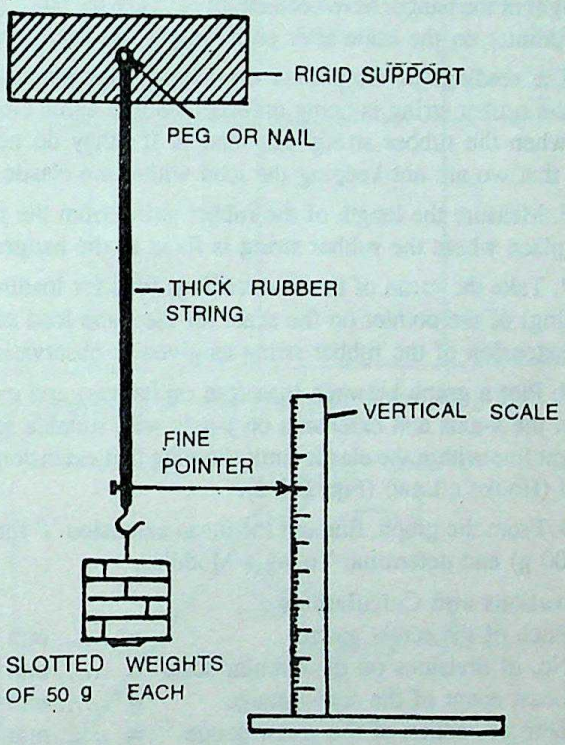

Fig. B- 7.1. Improvised apparatus for stress-strain relationship for rubber string

2. Find the diameter of the rubber string with the screw gauge at six different places when the hanger is not suspended. At each point, measure the diameter in two mutually perpendicular directions. While measuring the diameter, the string should not be pressed too hard.

3. Find the least count of the scale and suspend the hanger of the slotted weights (the hanger itself weighs 50 gm) gently and wait for some time so that the rubber string attains the full extension. Now read the position of the pointer on the vertical scale.

Place a 50 g weight in the hanger gently and wait for about 2 minutes. This will result in the extension of the rubber string. Note the reading of

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the pointer on the scale. The difference between the two readings on the scale gives the extension produced by 50 g load.

4. Now gradually increase the load in equal steps of 50 g upto the maximum permissible load and note the corresponding reading of the pointer on the scale each time.

5. Now remove the load in steps of 50 g weight till all weights except the weight of the hanger have been removed. Take the corresponding reading of the pointer on the scale after each weight has been removed.

The readings of the pointer on the scale for various weights taken when the rubber string is being unloaded should agree closely with those taken when the rubber string was loaded. If *they do not agree then it means that we are not keeping the load within the elastic limit.

6. Measure the length of the rubber string from the point of support to the place where the rubber string is fixed to the hanger.

7. Take the mean of the two readings (one for loading and other for unloading) of the pointer on the scale for the same load and calculate the mean extension of the rubber string as given in observation table.

8. Plot a graph between load (put on hanger) and extension, taking load on the x-axis and extension on y-axis with suitable scales. It will be a straight line within the elastic limit showing that extension is proportional to load (Hooke's Law) (Fig. B-7.2).

9. From the graph, find out the mean extension 'l' for a definite load (say 100 g) and determine Young's Modulus.

Observations and Calculations :

Pitch of the screw gauge = ... mm
No. of divisions on the circular scale = ... mm
Least count of the screw gauge = ... mm = ... cm
Zero correction of the screw gauge = ... mm

Diameter of the Rubber String :

S.No.	Reading along any diameter in cm	Reading along a perpendicular diameter in cm	Mean corrected diameter (d) in cm
1.			
2.			
3.			
4.			
5.			
6.			

*Particularly the zero weight in the hanger readings.

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Mean radius (r) = $\frac{d}{2}$ = ... cm

Length of the rubber string (*i*) ..... cm, (*ii*) ..... cm, (*iii*) ..... cm

Mean length of the rubber string = L = ... cm

Extension of the Rubber String :

S.No.	Weight in the hanger in g	Reading of the pointer on the vertical scale in cm		
		Loading (x)	Unloading (y)	Mean $\left(\frac{x+y}{2}\right)$
1.				
2.				
3.				
4.				
5.				
6.				

Determine the average value of extension 'l' for 100 g from the load-extension graph.

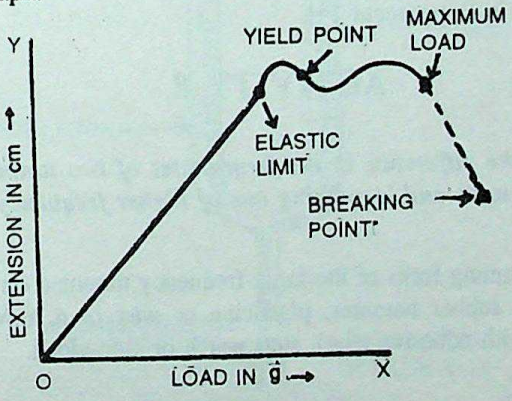

Fig. B-7.2. Stress-strain curve.

Substitute the values of M, L, l and r in formula

$$Y = \frac{Mg.L}{\pi r^2.l}$$ and calculate the value of 'Y'.

Result :

The Young's Modulus for the rubber string = ... dynes/cm^2

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Precautions :

1. The rubber string should not be loaded beyond elastic limits.

2. The loading and unloading should be done in equal steps (50 g) and it should be done gently and carefully.

3. After each addition or removal of the load, wait for some time in order to allow the string to increase or decrease in length.

4. The radius of the rubber string should be determined carefully at various points and at each point in two mutually perpendicular directions.

This is because a small error in the measurement of '*r*' will result in a large error in the value of 'Y'.

5. While measuring the radius, the string should not be pressed too hard.

6. The rubber string used should be sufficiently thick so that the extension produced by 50 g weight is not very large.

Sources of Error :

(*i*) Yielding of support and change in room temperature.

(*ii*) Change in the area of cross-section.

(*iii*) Weights used may not be standard weights.

ORAL QUESTIONS

[Same as in Experiment 19].

ACTIVITY 8

Aim :

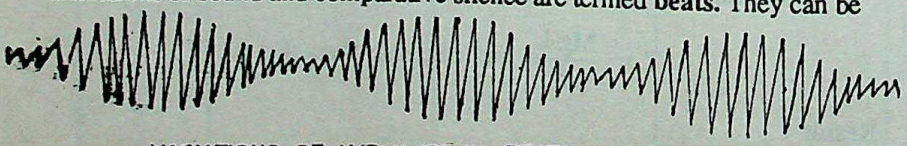
To find the difference in the frequencies of two tuning forks by counting their beats and identifying one of higher frequency.

Apparatus :

Two tall tuning forks of the same frequency mounted on resonating wooden boxes, rubber hammer, plasticine or wax or a movable mass (a small load with adhesive tape), stop watch or stop-clock.

Theory :

Beats : When two pure notes of nearly the same pitch are sounded together, periodic variations in the intensity of the sound are heard. These alterations of sound and comparative silence are termed beats. They can be



VARIATIONS OF AMPLITUDE IN BEATS

Fig. B-8.1

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plainly recognised when two tuning forks of nearly the same frequency are set in vibrations together. If the forks have frequencies N_1 and N_2 respectively, the **number of beats per second** is the difference between these frequencies, $n = N_1 - N_2$. Here N_1 is supposed greater than N_2.

This result can be explained by the principle of interference. The velocity of propagation is the same for the two notes, but the wavelengths differ slightly. Where the waves agree in phase they will strengthen each other, but where they are opposed they will neutralise one another (Fig. B-8.1). Let us take a starting point an instant when waves from the two sources reach the ear in the same phase. At the end of one second, the higher note has made N_1 complete vibrations, the lower note only N_2, that is, the higher note has made $(N_1 - N_2)$ more vibrations than the lower. During the second, one system of waves has been falling behind the other, and the loss amounts to $(N_1 - N_2)$ wave lengths. Hence there must have been $(N_1 - N_2)$ occasions in the course of the second when the two systems agreed in phase, and $(N_1 - N_2)$ occasions when the phases were opposed so that there was comparative silence. In other words, the number of beats in one second $n = N_1 - N_2$.

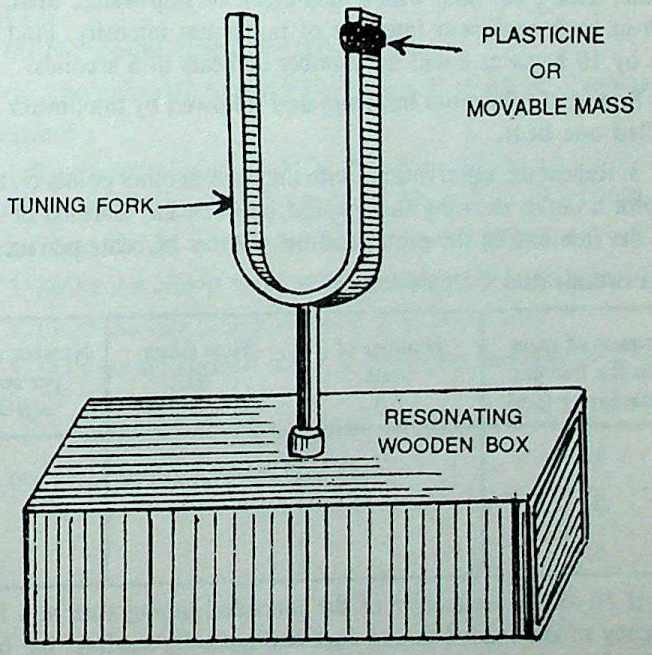

Fig. B-8.2.

If the two notes are nearly in unison, the beats are very slow and it is difficult to distinguish them. On the other hand, if the number of beats is more than four per second, it is difficult to count them. When the beats

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become so rapid that they cannot be separately perceived, a **discord** or **dissonance** is produced.

Procedure :

1. Take two tall tuning forks of the same frequency mounted on resonant wooden boxes. Make their frequencies slightly different by loading one by plasticine or wax or by tightly attaching a small load by adhesive tape so that it can be clamped at any part of the prong (Fig. B-8.2).

Note. Both the tuning forks must be of rather good quality and must give audible sound for about 8 to 10 seconds inspite of dissipation of energy in the resonating box.

2. Strike the tuning forks with a rubber hammer **in quick succession, with roughly equal force** ; carefully listen to the combined sound produced by the two tuning forks. Gradual increase and decrease in the intensity of sound will be heard. It is due to the beats produced by the superposition of waves of slightly different frequencies.

Count the number of beats in a measured interval of time. The number of beats per second should be determined by counting as many beats as possible, taking the time with a stop-clock or stop-watch. Start the stop-watch at each minimum intensity or maximum intensity. Find the time taken by 10 beats or count the number of beats in 5 seconds.

Sound of minimum intensity and followed by maximum intensity is called one beat.

3. Repeat the observations with the mass at other points on the prong and plot a curve showing the relation between the distance of the mass from the free end of the prong and the number of beats per second.

Observations and Calculations :

Distance of mass from the free end of the prong (cm)	Number of beats (a)	Time taken (t) in seconds	Number of beats per second $= n = a/t$
1.			
2.			
3.			

If N_1 is the frequency of the unloaded tuning fork and N_2 is the frequency of the loaded tuning fork and since by loading, the frequency gets decreased, so the turning fork of frequency N_1 is the one of higher frequency.

Number of beats per second $= n = N_1 - N_2 = \frac{a}{t}$ =

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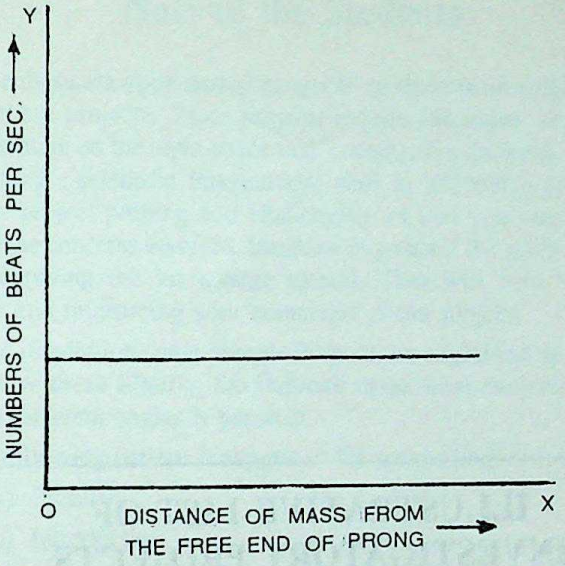

Fig. B-8.3.

Result :

(*a*) Number of beats per second = ...

(*b*) The unloaded tuning fork is the one of higher frequency.

Precautions :

1. Two tuning forks should be of **identical** frequency and should be of good quality giving audible sound for about 8 to 10 seconds.

2. There should be pin-drop silence in the laboratory.

3. Strike the tuning forks in quick succession with *equal* force.

4. Place the two tuning forks close to each other.

5. Start the stop-watch either at minimum intensity or at maximum intensity.

ORAL QUESTIONS

[Same as in Experiment No. 22]

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ILLUSTRATIVE LIST OF INVESTIGATORY PROJECTS

(One investigatory project is to be performed)

AND

SOME SAMPLE INVESTIGATORY PROJECTS

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Note to the Students

Since these are **open ended projects** so there is no single procedure for doing these projects. These projects require **intensive** reading of the modern literature on the topic concerned, constructive thinking, intelligence, good planning ; scientific imagination; skill to improvise apparatus etc. Make your project probing and challenging so that you may thoroughly understand the concepts involved. Inculcate in yourself the skills of collecting data and applying the knowledge gained. That will help you to gain confidence and reinforcing your command of the subject.

As an illustration some Sample Projects are explained. It is requested **not to follow these blindly.** Do improve upon these projects and attack them from different angles if possible.

The following pattern is suggested for proceeding with the Project :

(*i*) Problem
(*ii*) Introduction
(*iii*) Scope
(*iv*) Planning
(*v*) Setting and Execution
(*vi*) Presentation of Data
(*vii*) Conclusion
(*viii*) Discussion
(*ix*) References

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ILLUSTRATIVE LIST OF INVESTIGATORY PROJECTS

(Only **One** *to be done with the approval of the teacher)*

1. To study the changes in velocity of a body pulled by a constant force.
2. To study the conservation of energy of a simple pendulum using ticker timer and a tape.
3. To study the conservation of energy of a body falling freely, using ticker timer and tape.
4. To study the acceleration due to gravity with the help of a ball rolling down an inclined plane and by applying the correction for rotatory motion.
5. To study the acceleration of freely falling body using a ticker time and a tape.
6. To study the first law of motion by Galileo experiment using the double inclined track *i.e.*, a pair of inclined tracks each of which can be independently set at a small angle of inclination by plotting a graph between its sine (Perp./Hyp.) and the distance of ascent.
7. To estimate the size of a molecule of an oil.
8. To study the comparative cleansing effect of the different detergents through the study of surface tension.
9. To study the factors upon which the time period of a simple pendulum depends.
10. To study factors affecting the force of friction (static and kinetic) between two surfaces.
11. To study factors affecting rate of loss of heat (or rate of cooling) of a liquid.
12. To study the effect of surface on emission and absorption of radiation.
13. To study factors affecting the refractive index of a substance.
14. To study factors affecting resonant lengths of closed pipes.
15. To study thermocouple and the variation of thermo-emf with temperature.
16. To study the variations in the intensity of a source of light with distance.

Note. The above mentioned list suggests only specimens of Investigatory Projects. In order to promote innovativeness, the students are encouraged to take up *new* projects (*other than the ones mentioned above*) in consultation and with the approval of the teacher.

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SAMPLE PROJECT 1

Aim :

To draw the s-t graph and v-t graph of the motion of hand as one walks using ticker-time.

Apparatus :

Ticker-timer, paper tape, G-clamp, plug key.

Diagram :

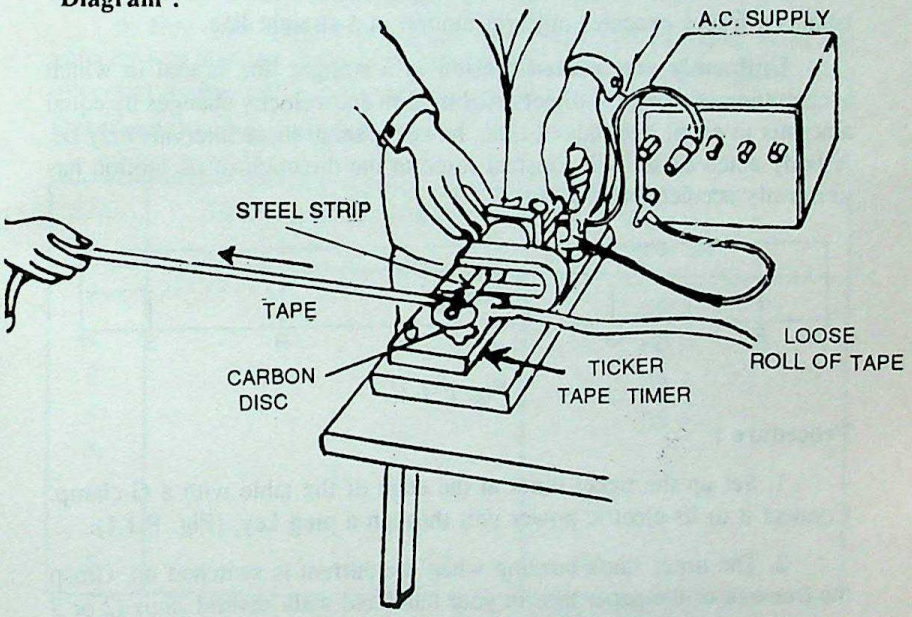

Fig. P-1.1. Ticker tape timer

Theory : Ticker-Tape Timer (Vibrator and ticker-tape) :

The ticker-tape timer is a device used for measuring time intervals of the order of 1/50 or 1/100 of a second. Ticker tape timers of different designs are available. The one shown in Fig. (P-1.1) has a vibrating steel strip which strikes a small carbon disc under which a paper-tape is pulled. The strip is made to vibrate with the help of an electromagnet at a known frequency. When run on 6 volt stepdown A.C. supply, its frequency is the same as that of the A.C. mains, *i.e.*, 50 hertz.

Another design is based on the electric bell, the gong being replaced by a mechanism of carbon disc and moving tape. Its frequency depends on mechanical properties of the hammer.

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Marks (or dots) are obtained on the tape at equal intervals of time—**each dot marks a complete vibration of the strip. The time interval between two dots on the tape can be taken as the unit of time for some of the experiments**, which you may call a **"tick".**

Note : The vibrator makes marks at equal *times* apart—and not necessarily at equal distances along the tape.

Uniform motion in a straight line is one in which a body covers equal distances in equal intervals of time, however small these intervals may be. A body not acted upon by any external force or acted upon by balanced forces executes uniform motion in a straight line.

Uniformly accelerated motion in a straight line is that in which acceleration is along the direction of motion and velocity changes by equal amounts in equal intervals of time, however small these intervals may be. A body acted upon by a constant force in the direction of its motion has uniformly accelerated motion.

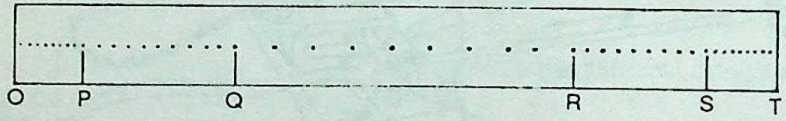

Fig. P-1.2.

Procedure :

1. Set up the ticker-timer at the edge of the table with a G-clamp. Connect it to its electric power unit through a plug key. (Fig. P-1.1).

2. The timer starts buzzing when the current is switched on. Grasp the free end of the paper tape in your hand and walk several steps (2 or 3 metres), with this hand on the hip and finally stop. You will get a series of dots on the paper tape as shown in Fig. P-1.2. The dots will have occurred at regular time intervals, but they will start **close** together, then be **farther apart.** Finally, the distance apart of dots will be very small.

3. The time interval between two consecutive dots on the paper tape will represent a unit of time, a **"tick"**. What is the distance covered during any five ticks ? Is it constant ? By inspecting the tape you can find (*i*) where the velocity was highest and where it was lowest, (*ii*) where the velocity was increasing and where it was decreasing ?

4. Choose a distinct dot on the tape close to starting point as the origin (O) and mark every 10th mark conspicuous by another mark (P, Q, R, ...) on it. Measure distance, s, of these marks from the origin and plot a s-t graph.

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5. Also find the average velocity during the intervals OP, PQ, QR, ... These average velocities may be taken as the instantaneous velocities at the middle of the corresponding time interval. Suppose, for example, distance PQ on the tape is 20 cm. There are 9 dots marked on the tape by the timer between P and Q, *i.e.*, time interval of 10 ticks had elapsed. Then average velocity between P and Q is $\frac{20}{10}$ = 2·0 cm per tick. It is roughly the actual velocity at an instant 5 ticks after the dot P was marked, *i.e.*, the instantaneous velocity at that time. In this manner compute data of instantaneous velocity versus time.

6. Now plot a v–t graph. From this graph you can find when the velocity was uniform. Also you can find from this graph, the regions (time intervals) during which the acceleration was highest and lowest.

Observations and Calculations :

For s–t graph

S.No.	Time interval in "ticks" (t)	Distance (s) in cm
1.		OP =
2.		PQ =
3.		QR =
4.		RS =
5.		⋮
6.		⋮
7.		⋮
8.		⋮

For v–t graph

S.No.	Time interval in "ticks" (t)	Instantaneous velocity (v) in "cm per tick"
1.		
2.		
3.		
4.		
5.		
6.		
7.		
8.		

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Result/Remarks :

(*i*) From *s*–*t* graph : .....

(*ii*) From *v*–*t* graph : .....

Precautions :

1. The tape should remain taut during the experiment even if you happen to swing your hand slightly. If you swing your hand too widely it is likely that for a short duration, resultant motion of your hand is backwards. The tape will get loose during backward motion and will, therefore, not move. If this happens, reject this tape, and record a second walk.

2. The time interval between two dots on the tape can be taken as a unit of time which you may call a "tick". Where the measured time must be converted into the standard unit, second, the time period of the vibrating steel strip of the timer must be measured.

ORAL QUESTIONS

Q. 1. *Define motion of a body ?*

Ans. The continuous change of position of a body with respect to another is called motion.

Q. 2. *Is there anything like absolute motion ?*

Ans. No ; all motion is relative.

Q. 3. *What is displacement of a body ?*

Ans. A change of position of a body from one point to another is called its displacement. It is described in terms of two quantities, a *distance* and a *direction*. The displacement of a body will change if there is any change in either its magnitude or direction or both.

Q. 4. *Define uniform motion of a body.*

Ans. An object that moves through equal distances in equal intervals of time, however small these intervals may be, is said to be in uniform motion.

Q. 5. *What is non-uniform motion ?*

Ans. When a body moves over unequal distances in equal intervals of time, it possesses non-uniform motion.

Q. 6. *Distinguish between speed and velocity.*

Ans. *Speed* is the ratio of the distance travelled by any object, irrespective of its direction, to the time it takes to travel that distance.

The *velocity* of a moving body is the rate of change of position of the body in a particular direction. In other words, the velocity of a moving body may also be defined as its speed in a particular direction.

Both are measured in ms^{-1} in SI units.

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Q. 7. *What is uniform velocity ?*

Ans. If a body not only traverses equal distances in equal intervals of time, however small these intervals may be, but also continues to move in the same direction, it is said to possess uniform velocity.

Q. 8. *Define instantaneous velocity of a body.*

Ans. The instantaneous velocity of a body is the actual value of the velocity of the body at any point of its path or at any instant of time.

Q. 9. *Define acceleration of a body.*

Ans. It is the rate of change of velocity of a body. Acceleration is the ratio of the change in velocity to the time over which this change occurs. Its S.I. unit is ms^{-2}.

Q. 10. *If the distance travelled by a body varied directly as the time, what conclusion do you draw about its motion and force ?*

Ans. The speed is *constant* and the force acting on it is *zero*.

Q. 11. *You observe an object covering distances in direct proportion to the square of time elapsed. What conclusion might you draw about its acceleration ? Is it increasing, decreasing, zero or constant ?*

Ans. The acceleration in this case is *constant*. If S is the distance covered and t, the time elapsed, then $S \propto t^2$ or $S = kt^2$ where k is a constant.

We also know that $S = \frac{1}{2}at^2$ where a is a uniform acceleration.

$\therefore \quad k = \frac{1}{2}a$, *i.e.*, a is constant.

Q. 12. *When does a body possess uniformly accelerated motion ?*

Ans. A body is said to move with uniformly accelerated motion if its velocity increases gradually i.e., increases by equal amounts in equal intervals of time, however small these intervals may be *e.g.*, a body falling freely under the action of gravity ; a steel ball rolling down an inclined plane etc.

Q. 13. *What was Galileo's best known contribution to the science of kinematics ?*

Ans. Galileo's best known contribution to the science of kinematics was his discovery that the free fall acceleration is exactly the same for any object. Given an absence of air resistance, each object will fall to earth with exactly the same acceleration *i.e.*, 9·8 ms^{-2}.

Q. 14. *State Newton's first law of motion or law of inertia.*

Ans. According to Newton's first law of motion, every body continues to be in its state of rest or of uniform motion in a straight line unless and until it is compelled by some external force to change its state of rest or of uniform motion.

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Q. 15. *State Newton's second law of motion.*

Ans. According to Newton's second law of motion, the rate of change of momentum produced in a body is directly proportional to the impressed force and takes place in the direction of the force applied.

Q. 16. *What do these laws give us ?*

Ans. Newton's first law of motion gives us the definition of force whereas Newton's second law of motion gives the measurement of force *i.e.*, F = *ma* where F is the force applied on a mass *m* and *a* is the acceleration produced in it.

Q. 17. *Define force and give its S.I. unit.*

Ans. Force is that agency which produces or tends to produce, destroys or tends to destroy motion in a body.

It is measured by the product of mass and acceleration. Its S.I. unit is *newton* (N).

Q. 18. *How is one newton related to dyne ?*

Ans. 1 newton = 10^5 dynes.

Q. 19. *Define energy. Give its S.I. and c.g.s. units.*

Ans. It is the capacity of a body to do work. S.I. unit of energy is *joule* (J) and c.g.s. unit of energy is *erg*.

Q. 20. *How joule and erg are related to each other ?*

Ans. 1 joule = 10^7 ergs.

Q. 21. *Name the two kinds of energy.*

Ans. Energy is of two kinds :

(*i*) Potential energy (P.E.)

(*ii*) Kinetic energy (K.E.)

Q. 22. *Define P.E. and mention its S.I. unit.*

Ans. Potential energy is the energy possessed by a body due to its position or configuration. P.E. of a body = *mgh* where *m* is the mass of the body, *g* is acceleration due to gravity and *h* is the height of the body from its zero level or mean position.

Its S.I. unit is *joule* (J).

Q. 23. *Define K.E. of a body and mention its S.I. unit.*

Ans. Kinetic energy of a body is the energy possessed by it due to its motion.

K.E. = $\frac{1}{2}mv^2$ where *m* is the mass of a body and *v* is its velocity. Its S.I. unit is *joule* (J).

Q. 24. *State law of conservation of energy.*

Ans. According to law of conservation of energy :

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(*a*) energy can neither be created nor destroyed ;

(*b*) the total amount of energy in this universe is constant ; and

(*c*) when a certain amount of energy in one form is expanded, its exact equivalent amount reappears in one or more of the other forms.

Q. 25. *What is the ultimate form of energy in all the interchanges in the form of energy ?*

Ans. Sooner or later, it assumes the form of *heat*, which in due course becomes distributed throughout space. It probably becomes unavailable, but is still there, though scattered.

Q. 26. *Enumerate two examples of law of conservation of energy.*

Ans. (1) A body falling freely under gravity.

(2) A vibrating pendulum.

Q. 27. *What is dissipation of energy ?*

Ans. The energy which disappears as heat and cannot be used again for any useful purpose is said to have been dissipated.

Q. 28. *What is transformation of energy ?*

Ans. It is the change of energy from one form to another. For example, when a body falls freely under gravity from a certain height, its P.E. changes into K.E. when it hits the ground.

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SAMPLE PROJECT 2

Aim :

To study the changes in velocity of a body pulled by a constant force and measure its acceleration.

Apparatus :

Ticker-timer, paper tape, a horizontal laboratory table, a trolley, a bumper, 3 cm thick strip of wood, three G-clamps, pulley fixed on the bumper, hanger, slotted weights (100 g each or 50 g each), few bricks, plug key and a spring balance.

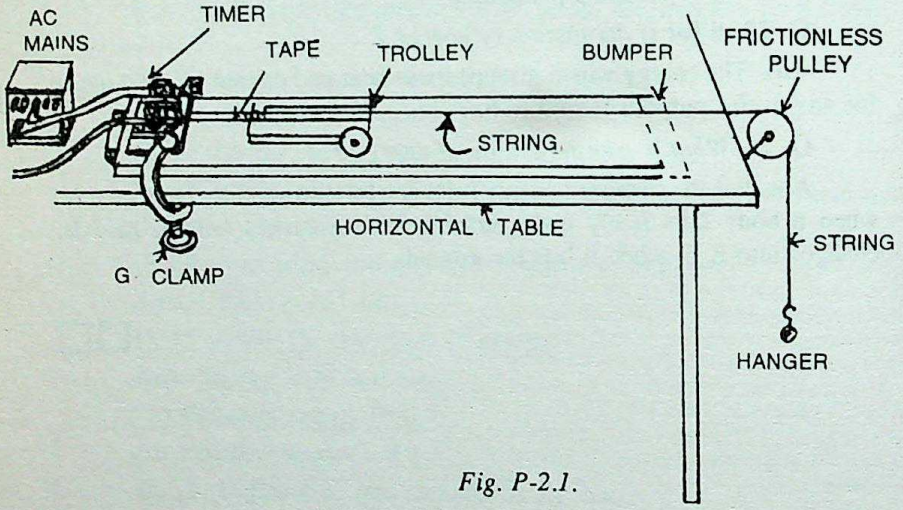

Fig. P-2.1.

Theory : Same as in Sample Project 1.

Procedure :

1. Fix a ticker-timer at one end of a laboratory table and a bumper at the other end with G-clamps. Place the trolley between them. Let it move from timer to the bumper, with the help of a thread passing over a **frictionless** pulley, at the other end of which is attached a hanger. **The run way is compensated for friction in the usual way.** Care must be taken that there is no drag by the ticker-tape comparable with the pulling load. In fact, the friction compensated should be arranged with the ticker tape in use.

2. Put slotted weights in the hanger. As it moves, the trolley pulls a length of tape through the ticker-timer. The mass of the pulley load must be only a very small fraction of the mass of the trolley.

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3. Keep the trolley initially at rest near the timer, with hanger in its highest position. After switching on the timer, release the trolley. If the trolley runs very fast keep one or two bricks over it. The trolley gains speed till the hanger reaches the ground and thereafter it is stopped by the bumper. Make a mark on the tape at the point which was under the vibrator of the timer, when hanger touches the ground. Marks made by the timer upto this point only are **useful as the force ceases to act after the hanger with weights touches the ground.** After the falling weight hits the ground, the trolley moves with a **constant velocity only.**

4. Choose a distinct mark on the tape close to starting point as the origin. Divide the entire motion in about 10 equal intervals of time. This can be done by counting equal number of dots, say 10, on the tape and marking the end-dot of each interval prominently.

5. Find the average velocity during each time interval ($v = s/t$) which is quite close to the instantaneous velocity at the middle of each time interval.

More details in this regard may be seen in Sample Project 1.

6. Plot a velocity versus time graph of the motion, taking a "tick" of the timer as the unit of time. Draw a smooth curve which best fits the points marked on the graph paper.

Find the slope at 5 or 6 different points along the entire curve. Find the average acceleration and estimate roughly the variation in it.

Observations and Calculations :

Constant force applied = mg = ... N

S.No.	Time interval in "ticks" (t)	Distance s in cm	Instantaneous velocity $v = \frac{s}{t}$ in "cm per tick"
1.			
2.			
3.			
4.			
5.			
6.			
7.			
8.			

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Slope of the Curve or Acceleration of the Body :

(*i*) Slope or acceleration = $\frac{AA'}{OA}$ = ... cm/tick^2

(*ii*) Slope = $\frac{BB'}{OB}$ = ... cm/tick^2

(*iii*) Slope = $\frac{CC'}{OC}$ = ... cm/tick^2

(*iv*) Slope = $\frac{DD'}{OD}$ = ... cm/tick^2

(*v*) Slope = $\frac{EE'}{OE}$ = ... cm/tick^2

$\therefore$ Average acceleration = ... cm/tick^2.

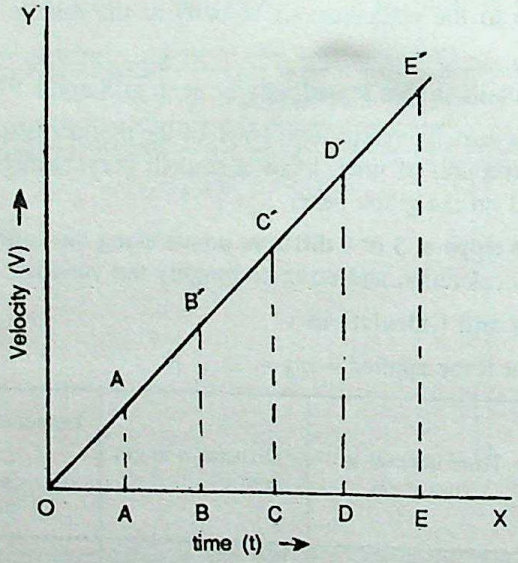

Fig. P-2.2.

Result :

(*i*) The velocity versus time graph of the motion of a body pulled by a constant force is a straight line. The slopes of v–t graph at various points are not different.

(*ii*) The average acceleration of the body when pulled by a constant force = ... cm/tick^2.

Precautions and Sources of Error :

1. Table must be clean, smooth and plane. The runway must be **compensated for friction.**

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2. In case trolley has to be made heavier by placing bricks, crumbly bricks may be wrapped in paper to prevent their grit from falling on the table and thus obstructing the smooth motion of the trolley.

3. If the slopes of *v–t* graph at various points are different *i.e.,* if the graph is not quite a straight line, the following is most likely the reason for variation in the acceleration of the trolley (*i*) air resistance; (*ii*) different friction at different spots, (*iii*) an uneven top table, and (*iv*) a constant force may produce different accelerations at different instants of time.

ORAL QUESTIONS

[Same as in Sample Project 1].

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SAMPLE PROJECT 3

Aim :

To study the conservation of energy of a simple pendulum using ticker timer and a tape.

Apparatus :

A brick, laboratory clamp stand, four G-clamps, ticker tape timer, strings, ticker tape, string of length 2 m, spring balance.

Diagrams :

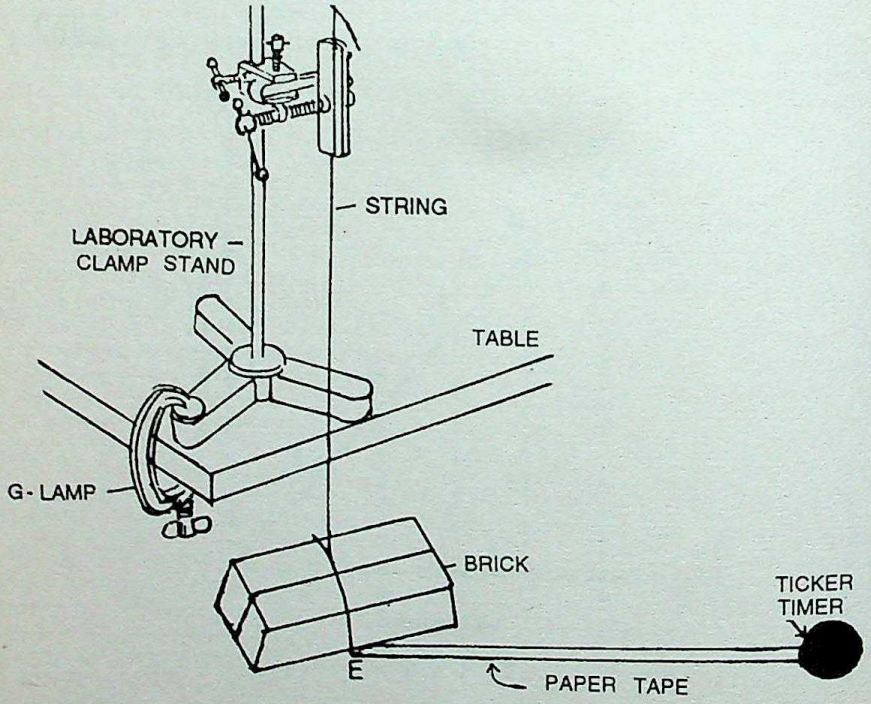

Fig. P-3.1.

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Theory :

(*a*) When a force moves a body, work is done on the body.

(*b*) When work is done on a body by a force, either its kinetic energy or potential energy increases or both increase.

(*c*) Total energy of a body in motion always remains constant if no external force acts on it though it may change from one form to another.

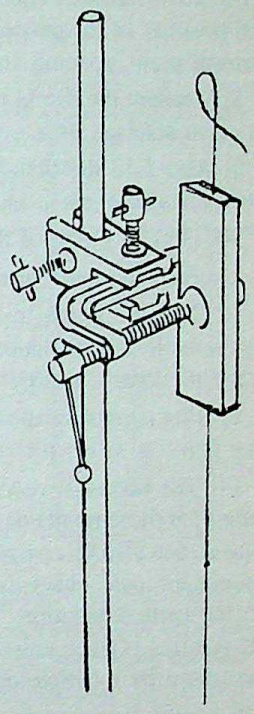

Fig. P-3.2.

Procedure :

1. Take a laboratory stand and clamp it firmly by a G-clamp to the edge of a table.

2. Make a heavy pendulum bob by tying a string to a brick. Hang it to the clamp stand as shown in Fig. P-3.1.

The more massive the support the more successful is the experiment. A light support allows energy to leak away. So does a loose support. Therefore, the pendulum cord should be firmly clamped at the top between two bits of metal or wood with their lower edges flush as shown in Fig. P-3.2.

3. To avoid the toppling of the stand, reinforce the vertical rod of the stand by tying its upper end with wires of soft iron to three G-clamps fixed on the edges of the table.

4. Adjust the length of the string such that the total length of the pendulum (*i.e.*, the length from the point of suspension to the centre of gravity of the heavy bob) is about 1·5 m.

5. Tie another string or thread through the middle of the brick such that the line of the thread passes through the c.g. of the brick.

6. Put the timer at about the same level as the lower surface of the brick. Attach the tape of the timer to the brick. Pull the thread passing through the c.g. aside such that the displacement of the brick is not more than 10° from the vertical. Hold the string there. The tape of the timer should also be taut.

7. Start the timer and let the thread go. As the brick moves to the other end, it pulls the tape through the timer and makes a record of the position of the brick at successive time intervals. When the brick reaches the far end, switch off the timer.

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On the record of the tape the extreme positions of the pendulum bob (brick) are represented by the two extreme dots on the tape. The central position of the pendulum is represented by the centre of the two extreme dots. Moreover, another check of the point on the tape corresponding to the central position of the pendulum is that at equal distances on either side of the central point, spacing among adjacent dots is equal.

8. Measure the displacements of the pendulum from the central point to 12 or so selected dots.

9. Also find the time when each of the selected dot was made, by counting dots from the central point.

10. Draw a graph of the displacement of the brick against time.

11. Find the mass of the brick with a spring balance.

12. Use the graph to find the velocity of the pendulum at 4 or 5 points on the left of the central position and 4 or 5 points on the right. Now calculate the kinetic energy (K.E.) at these points.

13. Plot a graph of the K.E. of the pendulum versus its position. Find out the point at which it is minimum.

14. The potential energy (P.E.) of the pendulum, at these points on which K.E. was calculated, can also be computed by knowing the height through which the brick is lifted above the central position. The P.E. at the central position is taken to be zero. The height can be found by a simple relation.

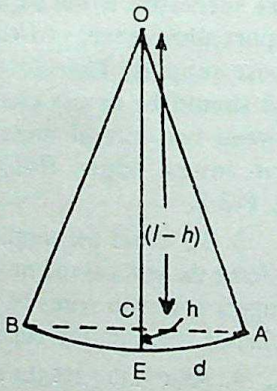

Fig. P-3.3.

If l is the length of the pendulum and d its horizontal displacement from the central position, then, the height h above the rest position (Fig. P-3.3) is found as follows :

$$OC \times CE = AC \times CB$$

$$(l - h) \times h = \sqrt{d^2 - h^2} \times \sqrt{d^2 - h^2}$$

$$lh - h^2 = d^2 - h^2 \qquad \therefore lh = d^2$$

or $$h = \frac{d^2}{l}$$

(This holds as long as d is small compared to l).

15. Draw a graph of P.E. versus position on the same graph on which K.E. versus position was drawn. Study the change in P.E. and K.E. and see how do they compare.

16. Find the sum of the K.E. and P.E. of the pendulum at the selected points.

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(If desired, the experiment can be made shorter by omitting the graphs for kinetic and potential energies. Instead total energy at the selected points may be calculated.)

Observations and Calculations :

Zero error of the spring balance = ... g

Mass of the brick : Observed = ... g Corrected = M = ... g

Side from Centre	S. No.	Displace-ment (d) in m	Time (t) in s	Velocity $v = \frac{d}{t}$ in m/s	V^2 in $(m/s)^2$	K.E. $= \frac{1}{2}mV^2$ in J	Height (h) in m	P.E. $=mgh$ in J	K.E. +P.E. in J
Left	1. 2. 3. 4.								
Right	1. 2. 3. 4.								

Result :

The sum total of mechanical energy (K.E. + P.E.) possessed by the simple pendulum at any point always remains constant within experimental error. Energy is neither being created or destroyed, it is being transformed from K.E. to P.E. and *vice-versa* with exact equivalence. Any increase in K.E. is exactly equal to the decrease in P.E. and *vice-versa*.

Precautions :

1. The displacement of the brick should not exceed 5° to 10° in order that (*i*) formula for calculation of h is valid and (*ii*) distances of dots on tape from central point truly represent corresponding displacements of the brick from its central position.
2. Length of the pendulum should be atleast 1·5 m.
3. The support should be rigid and massive.
4. Spinning of the bob (brick) must be avoided.
5. There must not be energy losses due to light and loose support.

□□

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SAMPLE PROJECT 4

Aim :

To study the conservation of energy of a body falling freely using ticker time and tape.

Apparatus :

Ticker-timer, tape, pulley or glass rod for paper tape to pass over it, an object of mass about 100 g (which can be easily suspended by the tape with a sellotape).

Theory :

Same as in Sample Project 3.

Procedure :

1. Clamp the ticker timer near the edge of the stool placed on the table so that the paper tape, after passing over the glass rod (or a glass tube or pulley) hangs vertically. The glass rod is used to reduce friction and save the tape from tearing.

2. Hang the object with the tape using a sellotape (Fig. P-4.1) Hold the spool of the tape in a horizontal axle clamped in a stand so that it feeds the tape into the timer without applying any significant drag while the body is falling freely.

3. Hold the body at rest by pressing the tape on to the open portion of the ticker-timer by the thumb. Start the ticker-timer and release the tape. **(It is advisable to cut off the appropriate length of tape from the reel before dropping the weight.)**

4. Find the velocity of the object at different heights above the ground (*i.e.* at a few selected dots on the tape corresponding to which height of the object above ground can be measured on the tape). Consider an equal number of dots, n, before a selected dot and after the selected dot. The distance covered by the object between these $(2n + 1)$ dots, S, is equal to the length of the tape between first and last of these dots. The time taken for moving the distance is equal to $2n$ times the period of the timer. Thus the velocity, v, of the object at the selected dot is $\frac{S}{2nT}$ where T is the time-period of the timer.

5. Calculate the K.E. of the body at each height using the formula K.E. = $\frac{1}{2}mv^2$ where m is the mass of the object.

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Also calculate the P.E. at all these heights for which K.E. has been calculated by using the formula, P.E. = mgh where h is the height of the object above the ground.

Diagram

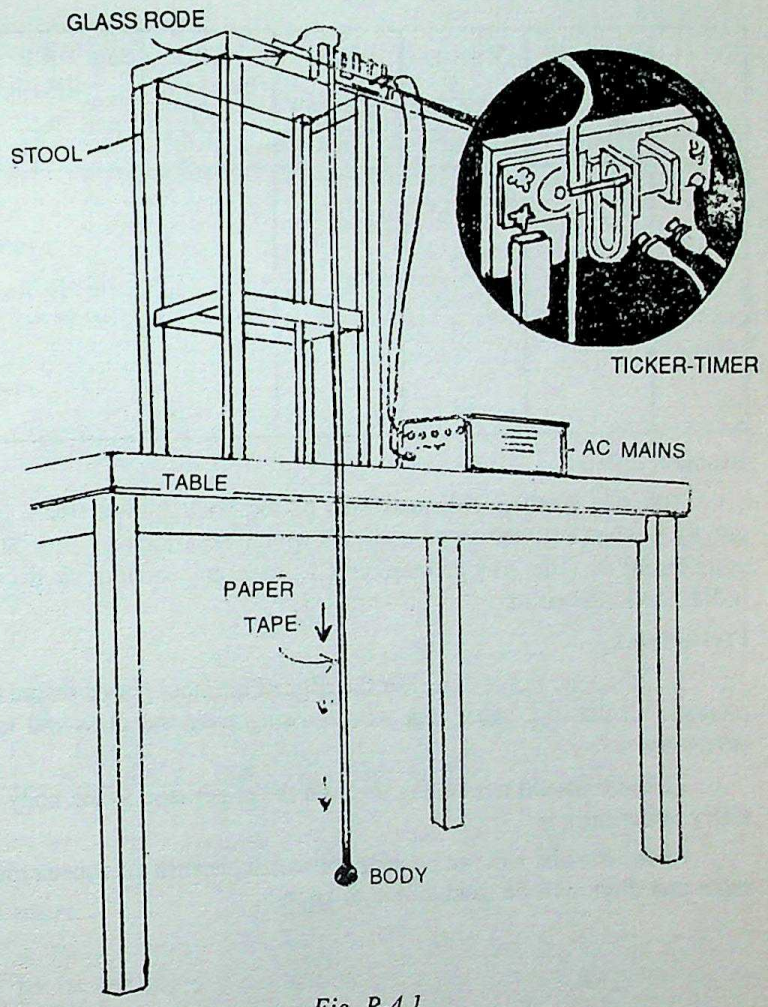

Fig. P-4.1.

6. Compare the K.E. with the P.E. at each dot. You may find that their sum is constant within experimental error.

Notes :

(*i*) Leave a few dots in the beginning of the motion, since they will be too close to each other and their analysis may be difficult.

(*ii*) After the body reaches the ground, mark a point on the tape below the vibrator of the timer. You need it for finding the height of the

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object above ground for various selected dots, But your last dot selected for finding the velocity of the body must be n dots before it.

Observations and Calculations :

Time period of the timer = ... seconds.

Dot No.	Height (h) above ground in m	Velocity $v = \frac{S}{2nT}$ in ms^{-1}	K.E. $E_k = \frac{1}{2} mv^2$ in J	P.E. $E_p = mgh$ in J	Sum = K.E. (E_k) + P.E. (E_p) in J

Result :

The sum total of K.E. and P.E. of the body falling freely under gravity is always found to be constant within experimental error at any point during its falls. Any increase in K.E. is exactly equal to the decrease in P.E. and *vice-versa.*

Precautions :

1. Clamp the ticker time near the edge of the stool placed on the table properly so that the paper tape after passing over the glass rod hangs vertically.

2. There should not be any *drag* on the paper tape as the body falls freely under gravity.

Note : Results will not be very consistent because the acceleration is large and there will be trouble due to friction.

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SAMPLE PROJECT 5

Aim :

To find acceleration due to gravity with the help of a ball rolling down an inclined plane and by applying the correction for rotatory motion.

Apparatus :

Double inclined track, steel ball of about 2·5 cm diameter, wooden blocks (2 cm high), 2 weights of 1 kg each, stop-watch and clean cotton cloth.

Theory :

If the motion of a body involves translation as well as rotation then the sum of its potential energy, kinetic energy of translation and kinetic energy of rotation is conserved provided energy is not lost in overcoming friction.

The acceleration of a body rolling down an inclined plane is less than $g \sin \theta$, as its P.E. is converted partly into rotational K.E. and partly into translational K.E.

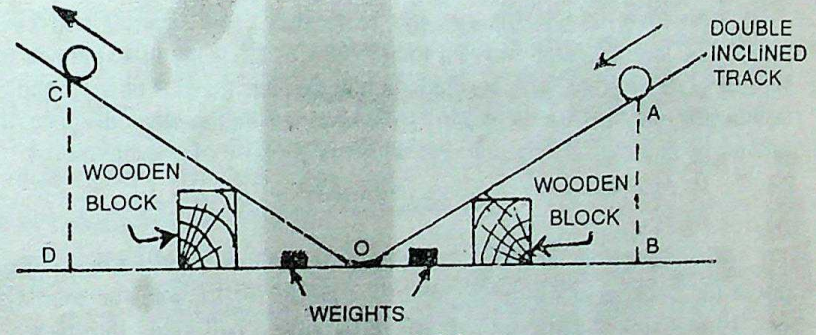

Fig. P-5.1.

Procedure :

1. Put the double inclined track on a table and keep the weights of 1 kg on the wings on either side of the middle of the track. Insert the wooden blocks under the ends of each track to incline the tracks (Fig. P-5.1).

Release the steel ball from, say 50 cm mark on the left track and notice the mark upto which it reaches on the right track. Now release the ball from the same mark (50 cm) from the right track and notice the mark upto which it reaches the left track. If the inclinations of both the tracks to

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horizontal is same then the ball would rise to the same mark on both tracks on releasing. Suppose the ball rises to smaller length on the right track in the former trial, it indicates that the inclination of the left track is less than that of the right track. If this is the case then push the block under the left track a little towards the centre, Repeat the above procedure till the inclination of both the tracks to horizontal is the same.

While rolling, if the ball wobbles laterally during its journey from one track to the other, adjust the weights in the centre of the track laterally till there is no wobbling. The wobbling happens if the ball has to bend slightly to left or to right while moving from one track to the other, in the centre of the tracks, *i.e.*, if the two tracks are not in the same vertical plane.

2. Now hold the ball near the end on one of the arms. Note the distance d_0 from the centre at which you will release the ball. Then release it and simultaneously start the stop-watch. As the ball moves to and fro, note the successive distances d_1, d_2, d_3, ... from the centre upto which it ascends (after each complete oscillation) on the arm on which it started. Also keep a count of the number of oscillations that the ball has made,. After, say, 4 oscillations of the ball, when you note the last distance d_4 upto which the ball ascends, simultaneously stop the watch. The last distance of ascent should not be less than $\frac{2}{3}$ of the starting distance.

3. In the first oscillation, the ball makes two upward and two downward journeys and moves a total distance $2(d_1 + d_1)$ as explained in Fig. P-5.1. Therefore, in 4 oscillations, the ball has made 8 upward and 8 downward journeys, *i.e.*, a total of 16 journeys. Find the mean distance, d, moved by the ball in one journey, which is (in case of 4 oscillations).

$$d = \frac{(d_0 + 2d_1 + 2d_2 + 2d_3 + d_4)}{8}$$

4. Find the mean time, T, taken by the ball for one journey up or down the track by dividing the total time by the total number of journeys *i.e.*, 16. Then calculate, a, the acceleration of the ball along the track :

$$a = \frac{2d}{T^2}$$

5. Repeat the experiment ten times. In each case, find the acceleration. Then find the mean of the several values so obtained.

6. If r be the radius of the ball and k is its radius of gyration then acceleration is given by the relation

$$a = \frac{r^2}{(k^2 + r^2)} g \sin \theta$$

This acceleration is less than $g \sin \theta$, the acceleration of a frictionless trolley moving down an inclined plane having same angle of inclination. It is due to the fact that the work done by the component of gravitational

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force along the direction of motion is partly converted into kinetic energy of translatory motion and partly into kinetic energy of rotatory motion of the ball.

For a solid sphere, $k^2 = 0{\cdot}4\ r^2$

Therefore, $$g = \frac{a(k^2 + r^2)}{r^2 \sin\theta} = \frac{1{\cdot}4a}{\sin\theta}$$

7. To determine the inclination sin θ, mark two points A and C on the two arms (Fig. P-5.1). Measure vertical heights AB and CD. Also measure distances of A and C from the centre O, where height is zero. Find the two inclinations $\frac{AB}{AO}$ and $\frac{CD}{CO}$ with respect to the table and find their mean. If the table is not horizontal, this mean value gives the correct inclination of each arm of the apparatus with respect to the horizontal plane.

Since the heights AB and CD are quite small in this experiment, the best way to measure them is as follows :

Take a metallic block. Without disturbing the blocks which make the two arms inclined, find by trial and error where does this metallic block fit below each arm. The two positions of the block give the lines AB and CD. AO and CO are then measured by markings on the inclinded tracks. AB and CD are equal to height of the metallic block which may be measured by a vernier callipers. Find several pairs of values by using metallic blocks of different heights and find their mean.

Observations and Calculations :

S.No	Number of oscillations completed by ball	Distance of ascent on the arm on which it started (cm)
1.	0	d_0 =
2.	1	d_1 =
3.	2	d_2 =
4.	3	d_3 =
5.	4	d_4 =

Total time for 4 oscillations = t = ... s

Mean time for one oscillation = $T = \frac{t}{4}$ = ... s

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Mean length of a single motion $= d = \dfrac{(d_0 + 2d_1 + 2d_2 + 2d_3 + d_4)}{8}$

$= \ldots\ldots$ cm

Acceleration of the ball $= a = \dfrac{2d}{T^2} = \ldots\ldots$ cms^{-2}

S.No.	Height of the block (cm)	Distance of upper edge from centre (cm)	Inclination	Mean Inclination	Inclination to horizontal sin θ
Inclination of left arm					
Inclination of right arm					

Mean inclination to the horizontal $= \sin\theta = \ldots\ldots\ldots$

Acceleration due to gravity $= g = \dfrac{1{\cdot}4\,a}{\sin\theta} = \ldots\ldots$ cms^{-2}

Result :

Acceleration due to gravity at ..... (place) = ... cms^{-2}

Value of acceleration due to gravity at ..... from tables

$= \ldots\ldots$ cms^{-2}

% error = ...

Precautions :

1. The track must be clean. Only then it will be possible to obtain 4 or 5 oscillations of the ball with the condition that the last distance of ascent is not less than about $\frac{2}{3}$ of the starting distance. If the last distance of ascent is too small, the approximations involved in calculating mean time and mean length of one motion are not valid.

Use a small cotton swab moistened in an organic solvent (*e.g.*, carbon tetrachloride) for cleaning it.

2. The inclination of both the tracks to the horizontal is required to be the same.

3. The ball should not wobble laterally as it moves from one track to the other.

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SAMPLE PROJECT 6

Aim :

To find the acceleration of a freely falling body using a ticker time and a tape.

Apparatus :

Ticker-tape, timer, glass rod or tube or pulley for paper tape to pass over it, an object of mass about 100 g of iron (or brass) which can be easily suspended by the tap.

Theory :

Due to gravitational attraction of earth, any object when allowed to fall freely moves vertically down with the same acceleration irrespective of its size and material. This acceleration, known as acceleration due to gravity, is uniform for experiments on laboratory scale.

Procedure :

1. Set up the apparatus as explained in Sample Project 4. Initially keep the body (100 g) hanging at rest by pressing the tape into the open portion of the ticker-timer by the thumb. Start the ticker-timer and release the body to let it fall to the ground.

2. Select 4 to 5 dots on a tape, roughly equally spaced in time, and find the velocity of the body at each of them as explained in Sample Project 4. Also find the time at which the body reached each of these dots, taking the origin of time at the first of these.

3. Plot a velocity-time graph for the motion of the body.

4. Find the slope of the graph to determine its acceleration.

Observations and Calculations :

Time period of the timer = ... s

S.No. of dot selected	Time when the body reached the selected dot	Velocity $V = \frac{s}{2nT}$ (in ms^{-1})

Slope of the graph $= \frac{dV}{dT} = \ldots\ldots\ ms^{-2}$

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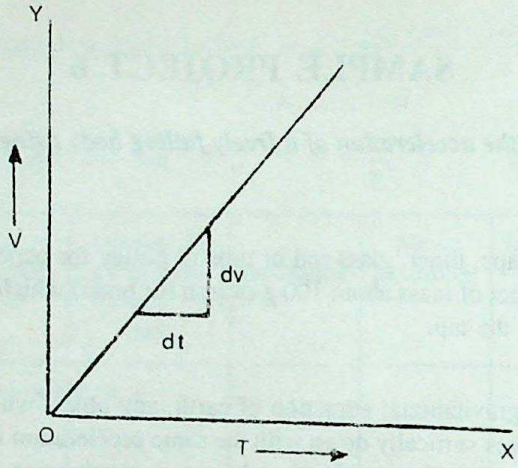

Fig. P-6.1.

Result :

The acceleration of the given freely falling body = ... ms^{-2}

Precautions :

1. Leave a few dots in the beginning of the motion since they would be too close together and their analysis may be difficult.

2. Notice the dot just before the object hits the ground. Discard the dots if any marked on the tape after the object touches the ground.

3. Clamp the ticker-timer near the edge of the table properly so that the paper tape after passing over the glass rod hangs vertically.

4. There should not be any drag on the paper tape as the body falls freely under gravity.

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SAMPLE PROJECT 7

Aim :

(a) To estimate the size of a molecule of an oil.

(b) To estimate the number of oil molecules in 1 gram-molecule.

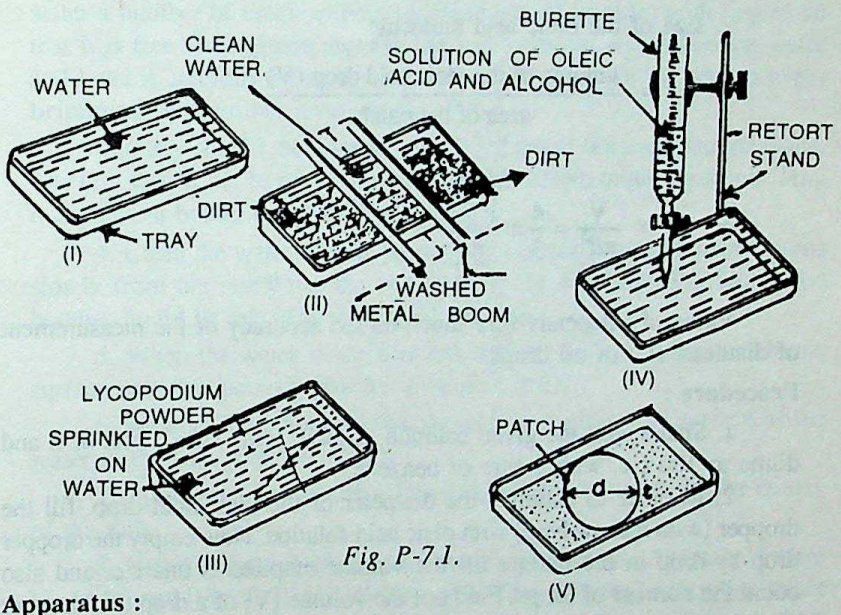

Fig. P-7.1.

Apparatus :

Burette, small beaker or conical flask, glass bottom tray (30″ × 30″) with graph paper attached to the underside, lycopodium powder, small measuring cylinder or pipette or dropper, solution of concentration 1 in 100 by volume of oleic acid in one litre of benzene, two waxed metal booms, cheese cloth cover, retort stand, metre rule, bucket, four rubber wedges, microscope, magnifying glass etc.

Theory :

According to Lord Rayleigh's work and of the assumption, or guess, that he made—**the oil spreads until it is a sheet one molecule thick.**

Allow one drop of given solution of oleic acid to fall on the water in a tray. It spreads over the surface equally in all directions forming a circular thin film of thickness (t) and diameter (d). Estimate the area of the patch of clear liquid formed. If the patch is roughly circular, we can measure its diameter. Hence, deduce the thickness of the layer of oleic acid. If we

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assure that the layer is one molecule thick, this gives one dimensions of the oleic acid molecule. (This will happen if the surface of water is grease free).

Area of the patch × thickness of the layer of oleic acid
= Volume (V) of the oleic acid drop
or
(size of the oleic acid molecule)

$\therefore$ size of the oleic acid molecule

$$= \frac{\text{volume of the oleic acid drop (V)}}{\text{area of the patch}}$$

or $$t = \frac{V}{\frac{\pi d^2}{4}} = \frac{4}{3}\pi \frac{\left(\frac{D}{2}\right)^3}{\frac{\pi d^2}{4}} = \frac{2}{3}\frac{D^3}{d^2}$$

Value of t depends very much on the accuracy of the measurement of diameter (D) of oil drops.

Procedure :

1. Shake well the given solution of oleic acid. Take 1 c.c. of it and dilute to 100 c.c. with 1 litre of benzene.

2. In order to estimate the diameter of the oleic acid drop, fill the dropper (with narrow bore) with oleic acid solution. Now empty the dropper drop-by-drop in the burette till the volume emptied is one c.c. and also count the number of drops. Find out the volume (V) of a drop that dropper gives.

Alternatively, we can also find the volume of the oleic acid drop as follows :

Take a wooden piece of about 4″ and 2·5″ and fix a nail on it. Make a loop of thin wire as shown in Fig. P-7.2.

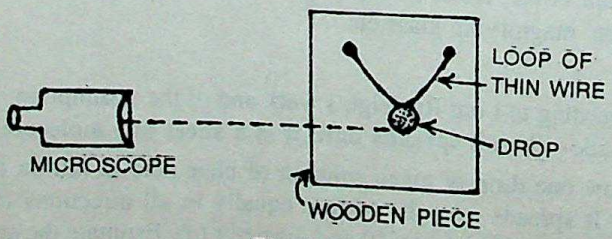

Fig. P-7.2.

A glass rod is dipped in the oleic acid solution and touched at the lower part of the wire so that the drop of suitable size is formed and its size adjusted by dragging more drops close to it or away from it.

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Now set the travelling microscope for the drop and measure its diameter (D) upto the accuracy of 0·001 cm and its volume is given by

$$V = \frac{4}{3}\pi\left(\frac{D}{2}\right)^3.$$

3. Place the given glass bottom tray (30″ × 30″ as used in photography), with graph paper attached to the underside, on the bench. The tray is cleaned with clear cotton and detergent powder and rinsed with water a number of times without touching any of its sides with fingers so that it is free from grease etc. Fill the tray partially with clean tap-water and level it carefully by using rubber wedges. Now fill the tray to **over-brimming** with further levelling Fig. P-7.1.

The tray should be a **large**, enamelled metal **tea** tray, painted black. The tray should not be of porous wood or plastic that might retain oil. Tray must have a **broad flat** and **rounded rim**.

4. Clean the water surface by moving the two * waxed metal booms slowly from the middle to the two ends of the tray [Fig. P-7.1(*ii*)]. The booms should be left near the end of the tray.

5. When the water in the tray has become quite steady sprinkle the surface with lycopodium powder. [Fig. P-7.1(*iii*)].

6. Arrange the burette so that its jet is just above the surface of the water in the tray [Fig. P-7.1 (*iv*)].

7. Allow **one** drop of the solution to fall on the water, **in the centre** of the tray.

8. Using the graph paper estimate the area of the **patch of clear liquid formed [Fig. P-7.1(*v*)]. If the patch is rough circular then use metre rod to measure the maximum diameter of the patch produced in two directions.

9. Deduce the thickness of the layer of oleic acid. If we assume that the layer is one molecule thick, this gives one dimension of the oleic acid molecule.

10. Knowing the density of oleic acid and assuming that its molecules are of roughly **cubic** shape, estimate the volume of one molecule and hence its mass. Knowing molecular weight of oleic acid, estimate the number of molecules in one gram-molecule.

---

*Melt paraffin wax in a can and carefully paint the booms with a layer of molten paraffin wax with a soft paint brush. If any difficulty in waxing is experienced, it is almost certainly due to not having the wax hot enough.

**With some water supplies, the patch contracts to a smaller size soon after it is formed. This is probably due to water-softening agents attacking the oleic acid, though this is not certain. Whatever the cause of such a contraction, we believe the proper measurement to take is the initial maximum diameter.

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Observations and Calculations :

Volume of one drop of oleic acid $= V =$ ..... cm^3

Area of the patch of clear liquid = ... cm^2
(using graph paper)

Or

For Roughly Circular Patch

Maximum diameter of the patch (roughly circular) on one side
$= d_1 =$ ..... cm

Maximum diameter of the patch on the other side
$= d_2 =$ ..... cm

Mean maximum diameter of the patch

$$= d = \frac{d_1 + d_2}{2} = \text{..... cm}$$

Area of the patch $\simeq d \times d =$ ..... cm^2

If we assume that the layer is one molecule thick, then,

Let thickness of the layer of the oleic acid
$= t$ cm (*i.e.*, the size of molecule)

Area of the patch $\times$ t = Volume of oleic acid drop (V)

$$\therefore \quad t = \frac{V}{\text{Area of the patch}} = \text{..... cm}$$

$$= \text{..... Å}$$

Thus the size of the oleic acid molecule = ...Å

Density of oleic acid = $0{\cdot}90 \pm 0{\cdot}01$ gm cm^{-3}. Assuming that the molecules of oleic acid solution are of roughly **cubic** shape.

The **volume of one** molecule $\simeq t^3 =$ ..... cm^3

$\therefore$ Mass of one molecule = $M = t^3 \times (0{\cdot}90 \pm 0{\cdot}01)$
= ..... g

Molecular weight of oleic acid = 282

$\therefore$ No. of molecules in one gram-molecule= .....

Result :

Roughly, the size of oleic acid molecule = ... Å

Roughly, the number of molecules in 1 gram–molecule of oleic acid
= .....

Note. Experimentally the value of diameter (d) of circular patch = 25 cm ; diameter of the oleic acid (D) = 0·095 cm and the molecular size t = 68 Å.

Precautions and Sources of Error :

1. The tray should be water-proof.

2. The water surface should be swept clean just before each student

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places his acid drop on it, by moving two water-proof waxed metal booms out from the centre to the ends.

3. The measurements are obviously rough but worth having. Treat the oil drop as a cube, or width equal to the diameter of the sphere (Fig. P-7.4). Treat the oil patch as a square instead of a circle (Fig. P-7.3) a square of width equal to the diameter of the circle. That will yield a smaller estimate of molecule—height, two-thirds of the proper result—but never mind, simplicity is best here.

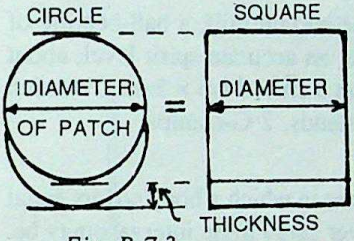

Fig. P-7.3.

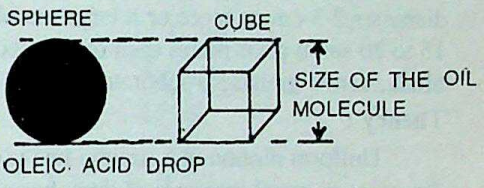

Fig. P-7.4.

4. The liquid should be dropped only drop-by-drop.

ORAL QUESTIONS

Q. 1. *What is the aim of this experiment ?*

Ans. To estimate the size of the molecule.

Q. 2. *What is a molecule ? What is molecular size ?*

Ans. Molecule is the smallest part of matter which can exist independently and continues to possess all the properties of the matter.

Molecular size means molecular diameter.

Q. 3. *Why should the oleic acid be diluted ?*

Ans. This is done to take a small trace of the oil even by trapping larger volume of the solution.

Q. 4. *What is the purpose of lycopodium powder in this experiment ?*

Ans. To have a circular patch of the clear liquid.

Q. 5. *What happens to benzene or alcohol in the film ?*

Ans. The benzene or alcohol contained in the drops evaporates partly and its remaining part gets dissolved in water, leaving behind only the oil molecules to spread over the surface of water.

Q. 6. *What type of substances whose molecular size you estimate are suitable for this experiment ?*

Ans. Those which spread into a circular film of *mono-molecular layer.*

Q. 7. *What is a mono-molecular layer ?*

Ans. A layer whose thickness is equal to the diameter of a molecule.

Q. 8. *As the molecules of oils and fats are not spherical, is the thickness of the mono-molecular layer equal to the smaller dimensions of the molecule ?*

Ans. No ; it is equal to the largest dimension of the diameter.

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SAMPLE PROJECT 8

Aim :

To study the first law of motion by Galileo's experiment, using the double inclined track (i.e., a pair of inclined tracks each of which can be independently set at a small angle of inclination).

Apparatus :

A double inclined track (or a flexible curtain rail), a ball-bearing of diameter 2·5 cm or more or a large marble, an accurate spirit level, about 15 to 20 small glass plates each of size about 3 cm × 3 cm × 2 mm, wooden block, screw gauge ; 2 laboratory clamp stands, 2 G-clamps.

Theory :

Uniform motion in a straight line is one in which a body covers equal distances in equal intervals of time, however small these intervals may be. A body not acted upon by an external force or acted upon by balanced forces executes uniform motion in a straight line.

According to Newton's first law of motion : "A body continues to be in a state of rest or of uniform motion in a straight line unless and until it is acted upon by an external force to change its state of rest or of uniform motion."

Diagram :

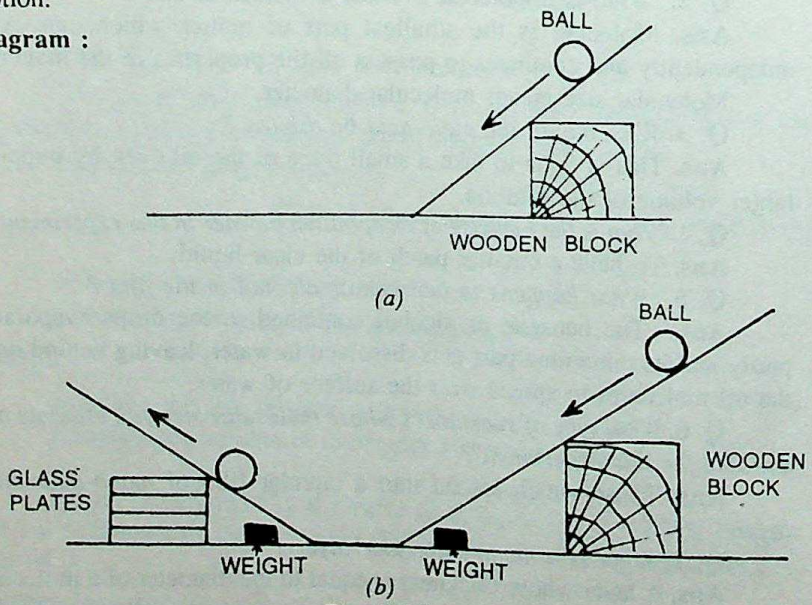

Fig. P-8.1.

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Alternative Set up of the Apparatus :

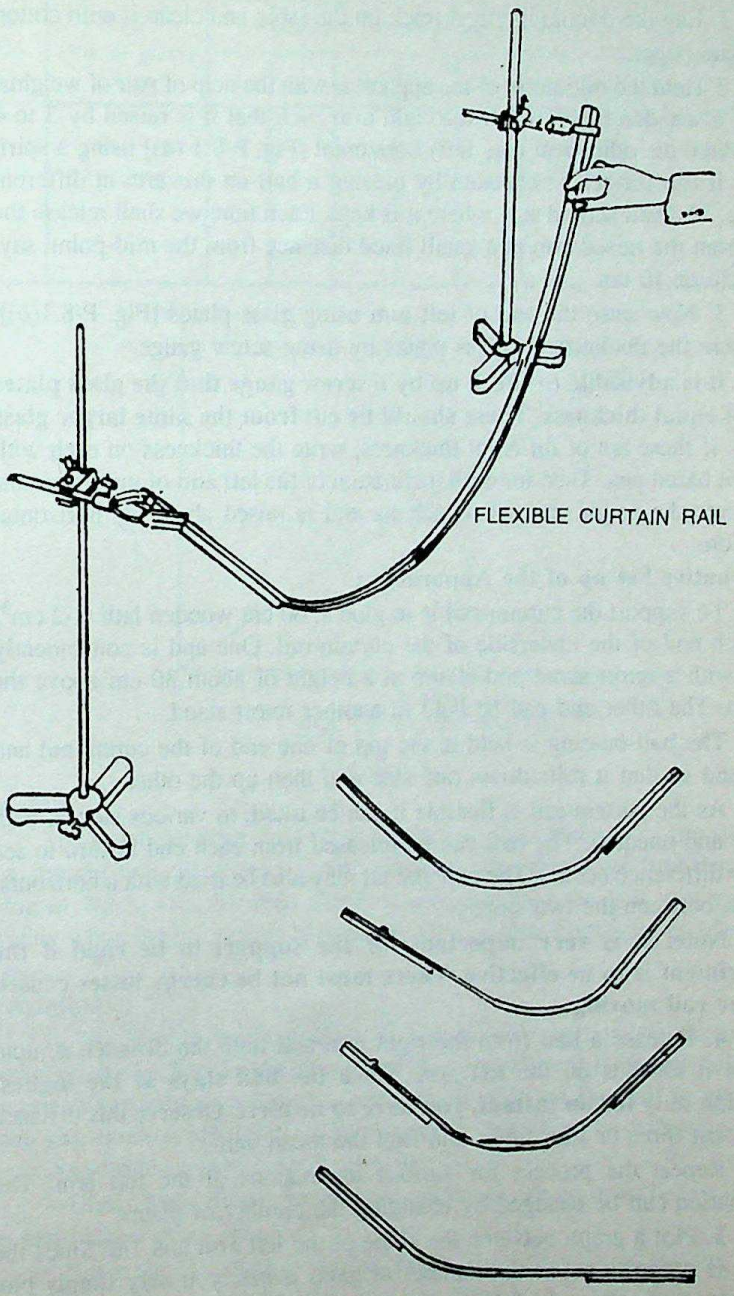

Fig. P.8.2

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Procedure :

1. Lay the double inclined track on the table and clean it with cotton or tissue paper.

2. Hold the mid-point of the apparatus with the help of pair of weights. Insert a wooden block under the right arm such that it is raised by 3 to 4 cm. Make the other arm (say left) horizontal [Fig. P-8.1 (*a*)] using a spirit level. It can further be checked by placing a ball on this arm at different places. The ball should stay where it is kept. Each time we shall release the ball from the raised arm at a small fixed distance from the mid-point, say, at 5 cm or 10 cm.

3. Now raise the end of left arm using glass plates [Fig. P-8.1(*b*)]. Measure the thickness of glass plates by using screw gauge.

It is advisable to check up by a screw gauge that the glass plates are of equal thickness. These should be cut from the same larger glass plate. If these are of different thickness, write the thickness on each with a spirit based pen. Then for each inclination of the left arm of the apparatus, calculate the height through which its end is raised above its horizontal position.

Alternative Set up of the Apparatus :

To support the curtain-rail is to glue a, 60 cm wooden lath (1·2 cm^2) to each end of the underside of the curtain-rail. One end is conveniently held with a retort stand and clamp at a height of about 30 cm above the bench. The other end can be held in another retort stand.

The ball-bearing is held at the top of one end of the curtainrail and released so that it rolls down one side and then up the other.

As the curtain-rail is flexible it can be tilted, to various slopes, both equal and unequal. The ball can be released from each end in turn to see if any difference occurs. The experiment may also be tried with a horizontal length between the two slopes.

Note. It is very important for the support to be rigid if the experiment is to be effective. There must not be energy losses caused by the rail moving.

4. Release a ball from the right arm and note the distance *d*, upto which it ascends on the left arm. **Since the ball stays at the highest position only for an instant, you have to be alert.** Observe this distance of ascent three or four times and find the mean value.

Repeat the process for various inclinations of the left arm. The inclination can be changed by changing the number of plates.

5. Plot a graph between the slope of the left arm and 1/*d*. Since the slope is proportional to the number of glass plates, you may simply plot 1/*d* versus number of glass plates. Extend the graph to slope zero *i.e.*, horizontal position of this arm.

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Observations and Calculations :

S. No.	Slope (No. of glass) plates	Distance of ascent (d) in cm						$1/d$ in cm^{-1}
		1	2	3	4	5	Mean	

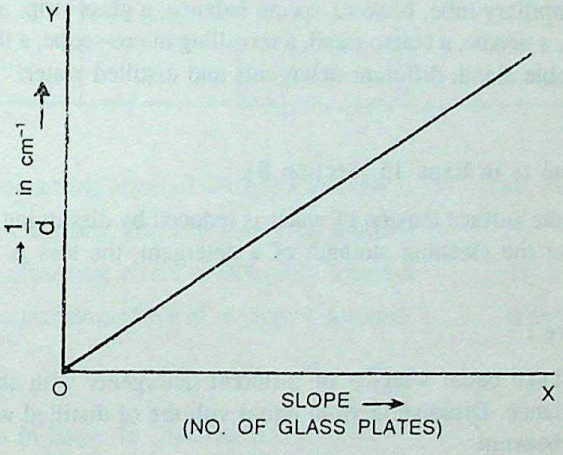

Fig. P-8.3.

Result :

The graph between $1/d$ versus number of glass plates (*i.e.*, the slope) is a straight line. By extending the graph to zero slope, we find that the value of $1/d$ is zero for zero slope. It indicates that the ball will go on moving when the left arm is horizontal. This is what First Law of Motion says.

Precautions :

1. The double inclined track or the flexible curtain rail must be properly cleaned. **Key to the success of this experiment is its low rolling friction. Even minute amount of dust or oil stain on the ball or on the track can cause much friction.** It is better to clean both by a tissue paper or cotton soaked in pure carbon tetrachloride.

2. Glass plates should be of equal thickness. These must be cut from the same larger glass plate.

3. Since the ball stays at the highest position only for an instant, one has to be alert to observe the distance of ascent.

4. The supports must be rigid. There must not be energy losses caused by moving of the rail.

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SAMPLE PROJECT 9

Aim :

To determine the comparative cleansing effect of the different detergents through the study of surface tension using capillary tube method.

Apparatus :

A capillary tube, beakers, spring balance, a glass strip, a thin rubber tube band, a needle, a clamp stand, a travelling micro-scope, a thermometer, an adjustable stand, different detergents and distilled water.

Theory :

Same as in Expt. 15 (Section B).

As the surface tension of water is reduced by dissolving a detergent, the greater the cleaning strength of a detergent, the less is its capillary rise.

Procedure :

1. Take equal weights of different detergents with the help of a spring balance. Dissolve them in **equal volume** of distilled water, kept in different beakers.

2. Compare the capillary rise of different solutions by dipping a capillary tube in each solution turn-by-turn **as per procedure explained in Experiment 15 (Section B).**

The capillary tube must be thoroughly cleaned and rinsed by distilled water. It must also be rinsed by distilled water before dipping it in each solution.

As the surface tension of water is reduced by dissolving a detergent, the greater the cleaning strength of a detergent, the less is its capillary rise.

Note : An **alternate method** is to have several capillary tubes of same internal diameter. These are cut from the same capillary tube. Then one capillary tube is dipped in each beaker. The beakers should be of same size and should contain equal volumes of different detergent solutions, so that the different capillary rise of different detergents is clearly visible even from a distance.

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Observations and Calculations :

Height of liquid column in the capillary tube :

Detergent Solution	Readings of microscope at		Height MN (or capillary rise) (h) in cm
	M	N	
(i)			
(ii)			
(iii)			
(iv)			

Result :

(a) The cleansing effect of detergent solution ..... is the maximum.

(b) The cleansing effect of detergent solution ..... is ..... .

(c) The cleansing effect of detergent solution ..... is ..... .

(d) The cleansing effect of detergent solution ..... is the least of all.

Precautions :

Same as in Expt. 15 (Section B)

Sources of Error :

Same as in Expt. 15 (Section B)

ORAL QUESTIONS

Same as in Expt. 15 (Section B)

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SAMPLE PROJECT 10

Aim :

To study the factors affecting rate of loss of heat (or rate of cooling) of a metal.

Apparatus :

Aluminium block A of mass 1 kg and aluminium block B of mass about 100 g, as nearly as possible the same shape and proportions as the larger block ; 2 thermometers 0–100°C ; large pan of hot water ; expanded polystyrene or cork mat ; ruler ; top-pan balance ; two stop-clocks. Both blocks must be drilled to take a thermometer.

Method :

1. *Keep the two blocks in hot water (over a low flame or with an immersion heater if necessary) for about 10 minutes before the project begins. The water need not be boiling.*

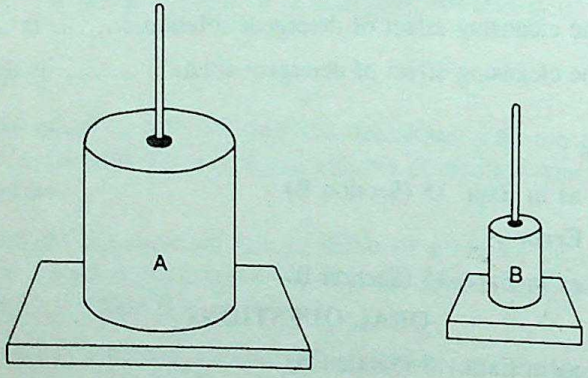

Fig. P-10.1.

2. Check that the two blocks in the hot water are at roughly the same temperature by putting thermometers in the holes in each block. Then take the blocks out of the water, and stand them (not too close) on insulating mats.

Use the two stop-clocks to record the time taken for each block to cool from one temperature to another about 5°C below it. Make the starting temperature as high as possible, to save time :

	Large block	Small block
Time to cool from .....°C to .....°C	..... s	..... s

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3. Weigh the two blocks, and work out the ratio of their masses. Measure their dimensions, and work out the ratio of their *surface areas*. Explain how you work out the ratio of the areas. Explain why the two ratios are not the same, even though the blocks are made of the same material (aluminium).

Masses ..... kg and ..... kg

Ratio of masses .....

Dimensions .....

Ratio of surface areas .....

Explanation of calculation .....

Reason why the two ratios are different.....

4. Suppose that the amount of energy radiated and convected away per second is proportional to the surface area, at a definite temperature. If so, what is the ratio of the energy (heat) lost per second by the two blocks ? Which loses the larger amount of energy per second ?

Ratio of energy lost per second .....

Explanation .....

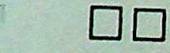
5. If the two blocks lost the same amount of energy, which would cool by the greater amount ? Explain. Use this explanation to suggest how to explain the ratio of the two rates of cooling observed in step 1. If possible, calculate the ratio from the data in steps 2 and 3, and compare it with what you observed.

Explanation of cooling when the same energy is lost

.....

Explanation of why one block cools more quickly than the other

.....



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APPENDICES

TABLES OF PHYSICAL CONSTANTS

TABLE 1
Densities of Some Common Substances in kg. m^{-3} (at 293 K)

Asbestos	= 2400	Graphite	= 2300
Alcohol (ethyl)	= 790	Glass (Crown)	= 2500
Alcohol (methyl)	= 810	Glass (Flint)	= 2900 to 4500
Alum	= 2500	Glass (Common)	= 2400 to 2800
Aluminium	= 2700	Ice	= 916
Coal	= 1200 to 1500	Platinum	= 21850
Wood	= 600 to 800	Rubber (India)	= 910 to 950
Iron (wrought)	= 7850	Sand	= 2300 to 2600
Iron (cast)	= 7600	Marble	= 2500 to 2800
Brass	= 8400 to 8700	Mercury	= 13600
Copper	= 8900	Lead	= 11370
Cork	= 180 to 260	Copper Sulphate Crystal	= 2100
Coin (old)	= 10300	Silver	= 10500
Sugar	= 1590	Kerosene Oil	= 800
Steel	= 7700	Turpentine Oil	= 870
Stainless steel	= 7800	Olive Oil	= 900
Glycerine	= 1260	Wax	= 900
Spirit	= 830	Milk	= 1030
Petrol	= 800	Zinc	= 7100
Sod. chloride	= 2150	Manganin	= 8500
Gold	= 19300		

TABLE 2
Acceleration due to gravity at different places in India along with their Latitude, Longitude and Elevation

Place	*g* (m/s^2)	*Lat.* (*N*)	*Long.* (*E*)	*Elevation* (*m*)
Agra	9.7905	27°12′	78°02′	158
Aligarh	9.7908	27°54′	78°05′	187
Allahabad	9.7894	25°27′	81°51′	94
Banaras	9.7893	25°20′	83°00′	81
Bombay	9.7863	18°54′	72°49′	10
Calcutta	9.7880	22°35′	88°20′	6

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Delhi	9.7914	28°40′	77°14′	216
Equator	9.7805	00°00′	na	0
Jaipur	9.7900	26°55′	75°47′	433
Udaipur	9.7881	24°35′	73°44′	563
Srinagar	9.7909	34°05′	74°50′	159
Pole	9.8322	90°00′	na	0
Madras	9.7828	13°04′	80°15′	6
Trivandrum	9.7812	8°28′	76°58′	27
Tirupati	9.7822	13°38′	79°24′	169
Madurai	9.7810	9°55′	78°07′	133
Bangalore	9.7803	12°57′	77°37′	915
Gauhati	9.7899	26°12′	91°45′	52
Bhubaneswar	9.7866	20°28′	85°54′	23

TABLE 3

Variation of atmospheric Temperature and Pressure with Altitude

(At sea level pressure = Standard Atmosphere and Temperature = 15°C assum.)

Altitude (*metres*)	*Pressure* (*millibars*)	*Temperature* (°C)
0	1013.25	15.0
250	983.58	13.4
500	854.61	11.8
750	926.34	10.1
1000	898.75	8.5
1500	825.56	5.2
2000	794.95	2.0
2500	746.82	−1.2
3000	701.08	−4.5
3500	657.64	−7.8
4000	616.40	−11.0
4500	577.28	−14.2
5000	540.20	−17.5
6000	471.81	−29.0
7000	410.61	−30.5
8000	356.00	−37.0
9000	307.42	−43.5
10000	264.36	−50.0

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TABLE 4
Surface Tension of Liquids

Substance	*In contact with*	*Temp* (°C)	*Surface Tension* (10^{-3} Nm^{-1})
Water	Air	10	74.22
	Air	20	72.55
	Air	30	71.18
	Air	40	69.56
	Air	50	67.91
Acetic acid	Vapour	10	28.8
	Vapour	20	27.8
	Vapour	50	24.8
Ethyl Alcohol	Air	0	24.05
	Vapour	10	23.61
	Vapour	20	22.75
	Vapour	30	21.89
Glycerol	Air	20	63.4
	Air	90	58.6
Methyl Alcohol	Air	0	24.49
	Air	20	22.61
	Vapour	50	20.14
Mercury	Vapour	20	470
	Vapour	100	456
Oleic acid	Air	20	32.5
Kerosene	Air	20	24
Turpentine	Air	20	27

TABLE 5
Elastic Properties of Solids

Substance	*Young's Modulus* (10^{10} Nm^{-2})	*Modulus of rigidity* (10^{10} Nm^{-2})	*Bulk Modulus* (10^{10} Nm^{-2})	*Breaking Stress* (kg/mm^2)
Aluminium	7.03 to 7.05	2.61	7.55	20 to 25
Brass (70/30)	10.06	3.73	11.18	30 to 50
Cropper	12.98	9.83	13.78	40 to 45
Gold	7.8	2.7	21.7	—
Iron (soft)	21.14	8.16	16.98	—
Silver	8.27	3.03	10.36	—
Steel (mild)	21.19	8.22	16.92	40 to 45
Silver	7.1 to 7.4			28
Rubber	0.05	0.00015	—	—
Wood (oak)	1.3	—	—	—
Wood (teak)	1.7	—	—	—
Glass	5.1—7.1	3.1	3.75	—
Quartz	5.4	3.4	—	—

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TABLE 6
Velocity of Sound
(At 20°C unless otherwise stated)

Substance	*Velocity of longitudinal wave* (ms^{-1})	*Substance*	*Velocity of longitudinal wave* (ms^{-1})
Alcohol	1177	Hydrogen (0°C)	1284
*Aluminium	5240	*Iron	5170
Air (0°C)	331.45	Mercury	1451
*Brass	3130–3450	Nitrogen (0°)	334
*Copper (annealed)	3790	*Steel (tool)	5150
Carbon dioxide (0°C)	259	Water	1484
*Glass, Crown	4710–5300	Water vapour (100°C)	405
*Glass, flint	3490–4550	Oxygen (0°C)	316

TABLE 7
Standard Wire Gauge

Size (S.W.G.)	*Diameter* (mm)	*Size (S.W.G.)*	*Diameter* (mm)
1	7.62	21	0.813
2	7.01	22	0.711
3	6.40	23	0.610
4	5.89	24	0.559
5	5.38	25	0.508
6	4.88	26	0.457
7	4.47	27	0.417
8	4.06	28	0.376
9	3.66	29	0.345
10	3.25	30	0.315
11	2.95	31	0.295
12	2.64	32	0.274
13	2.34	33	0.254
14	2.03	34	0.234
15	1.83	35	0.218
16	1.63	36	0.198
17	1.42	37	0.173
18	1.22	38	0.152
19	1.02	39	0.132
20	0.914	40	0.122

*In case of solids velocities of longitudinal waves in thin rods are quoted.

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TABLE 8
Coefficient of friction of common things

Substance	*Condition*	*Coefficient of dynamic friction*
Glass on glass	Clean and dry	0.18
Wood on glass	Clean and dry	0.2 to 0.3
Wood on wood	Clean and dry	0.25—0.5
Wood on steel	Clean and dry	0.20 to 0.25
Steel on steel	Clean and dry	0.17—0.23
Steel on steel	Greased	0.05
Stone on concrete	Dry	0.45
Car tyre on concrete	Moderate speed	0.40

TABLE 9
Coefficient of expansion

Solids	*Coefficient of linear expansion* $10^{-6}\ K^{-1}$	*Liquids*	*Coefficient of volume expansion* $10^{-4}K^{-1}$
Aluminium	24	Alcohol (ethyl)	11.2
Brass	18 to 19	Alcohol (methyl)	12.2
Copper	16.7	Benzene	12.4
Constantan	18	Ether (ethyl)	16.3
Glass (pyrex)	3	Glycerine	5.3
Glass (soft soda)	8.5	Mercury	1.8
Iron (cast)	10.0	Water (15°C)	1.5
Iron (wrought)	12.0	Water (99°C)	7
Ice	51.0	Kerosene Oil	10.0
Steel	11.0	Turpentine	9.4
Lead	23.0	Olive Oil	7.2
Zinc	28.0		
Platinum	8.9		
Silver	19.2		

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TABLE 10
Density of Water at Various Temperatures (in gm/cm^3)

Temp °C	0	2	4	6	8	10	12	14	16	18
0	.99987	.99997	1.00000	.99997	.99988	.99973	.99953	.99927	.99897	.99862
20	.99822	.99780	.99732	.99681	.99626	.99567	.99505	.99440	.99371	.9930
40	.9922	.9915	.9907	.9898	.9890	.9881	.9872	.9862	.9853	.9843
60	.9832	.9822	.9811	.9801	.9787	.9778	.9767	.9755	.9743	.9731
80	.9718	.9706	.9693	.9680	.9667	.9653	.9640	.9626	.9612	.9598
100	.9584	—	—	—	—	—	—	—	—	—

TABLE 11
Boiling Points of Water at Various Barometric Heights

mm	0	1	2	3	4	5	6	7	8	9
700	97.709	748	788	827	866	906	945	984	98.023	062
710	98.102	141	180	219	258	296	335	374	413	451
720	98.490	529	567	606	644	683	721	759	798	816
730	98.874	912	950	989	99.027	065	102	140	178	216
740	99.254	292	329	367	405	442	480	517	554	592
750	99.629	666	704	741	778	815	852	889	926	963
760	100.00	037	074	110	147	184	220	257	294	330

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TABLE 12
Vapour Pressure of Water at Various Temperatures

Temp. °C	0	1	2	3	4	5	6	7	8	9
0	4.579	4.924	5.290	6.681	6.097	6.541	7.011	7.511	8.042	8.606
10	9.205	9.840	10.513	11.226	11.980	12.779	13.624	14.517	15.460	16.456
20	17.51	18.62	19.79	21.02	22.32	23.69	25.13	26.65	28.25	29.94
30	31.71	33.57	33.53	37.59	39.75	42.02	44.40	49.90	49.51	52.26
Tem. °C	**0**	**2**	**4**	**6**	**8**	**10**	**12**	**14**	**16**	**18**
40	55.13	61.30	68.05	74.43	83.59	92.30	101.9	112.3	123.6	135.9
60	149.2	163.6	179.1	195.2	214.0	233.5	254.5	277.1	301.3	327.2
80	335.1	384.8	416.7	450.8	487.1	525.8	567.1	611.0	657.7	707.3

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APPENDIX

Logarithm Tables

LOGARITHMS

	0	1	2	3	4	5	6	7	8	9	1 2 3	4 5 6	7 8 9
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374	5 9 13 4 8 12	17 21 26 16 20 24	30 34 38 28 32 36
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755	4 8 12 4 7 11	16 20 23 15 18 22	27 31 35 26 29 33
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106	3 7 11 3 7 10	14 18 21 14 17 20	25 28 32 24 27 31
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430	3 6 10 3 7 10	13 16 19 13 16 19	23 26 29 22 25 29
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732	3 6 9 3 6 9	12 15 19 12 14 17	22 25 28 20 23 26
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014	3 6 9 3 6 8	11 14 17 11 14 17	20 23 26 19 22 25
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279	3 6 8 3 5 8	11 14 16 10 13 16	19 22 24 18 21 23
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529	3 5 8 3 5 8	10 13 15 10 12 15	18 20 23 17 20 22
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.88	7586	7603	7621	7638	7656	7674	7691	7709	7727	7745	2 4 5	7 9 11	12 14 16
.89	7762	7780	7798	7816	7834	7852	7870	7889	7907	7925	2 4 5	7 9 11	13 14 16
.90	7943	7962	7980	7998	8017	8035	8054	8072	8091	8110	2 4 6	7 9 11	13 15 17
.91	8128	8147	8166	8185	8204	8222	8241	8260	8279	8299	2 4 6	8 9 11	13 15 17
.92	8318	8337	8356	8375	8395	8414	8433	8453	8472	8492	2 4 6	8 10 12	14 15 17
.93	8511	8531	8551	8570	8590	8610	8630	8650	8670	8690	2 4 6	8 10 12	14 16 18
.94	8710	8730	8750	8770	8790	8810	8831	8851	8872	8892	2 4 6	8 10 12	14 16 18
.95	8913	8933	8954	8974	8995	9016	9036	9057	9078	9099	2 4 6	8 10 12	15 17 19
.96	9120	9141	9162	9183	9204	9226	9247	9268	9290	9311	2 4 6	8 11 13	15 17 19
.97	9333	9354	9376	9397	9419	9441	9462	9484	9506	9528	2 4 7	9 11 13	15 17 20
.98	9550	9572	9594	9616	9638	9661	9683	9705	9727	9750	2 4 7	9 11 13	16 18 20
.99	9772	9795	9817	9840	9863	9886	9908	9931	9954	9977	2 5 7	9 11 14	16 18 20

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NATURAL SINES

Degrees	0' 0°.0	6' 0°.1	12' 0°.2	18' 0°.3	24' 0°.4	30' 0°.5	36' 0°.6	42' 0°.7	48' 0°.8	54' 0°.9	Mean Differences 1 2 3	4 5
0	·0000	0017	0035	0052	0070	0087	0105	0122	0140	0157	3 6 9	12 15
1	·0175	0192	0209	0227	0244	0262	0279	0297	0314	0332	3 6 9	12 15
2	·0349	0366	0384	0401	0419	0436	0454	0471	0488	0506	3 6 9	12 15
3	·0523	0541	0558	0576	0593	0610	0628	0645	0663	0680	3 6 9	12 15
4	·0698	0715	0732	0750	0767	0785	0802	0819	0837	0854	3 6 9	12 15
5	·0872	0889	0906	0924	0941	0958	0976	0993	1011	1028	3 6 9	12 14
6	·1045	1063	1080	1097	1115	1132	1149	1167	1184	1201	3 6 9	12 14
7	·1219	1236	1253	1271	1288	1305	1323	1340	1357	1374	3 6 9	12 14
8	·1392	1409	1426	1444	1461	1478	1495	1513	1530	1547	3 6 9	12 14
9	·1564	1582	1599	1616	1633	1650	1668	1685	1702	1719	3 6 9	12 14
10	·1736	1754	1771	1788	1805	1822	1840	1857	1874	1891	3 6 9	12 14
11	·1908	1925	1942	1959	1977	1994	2011	2028	2045	2062	3 6 9	11 14
12	·2079	2096	2113	2130	2147	2164	2181	2198	2215	2232	3 6 9	11 14
13	·2250	2267	2284	2300	2317	2334	2351	2368	2385	2402	3 6 8	11 14
14	·2419	2436	2452	2470	2487	2504	2521	2538	2554	2571	3 6 8	11 14
15	·2588	2605	2622	2639	2656	2672	2689	2706	2723	2740	3 6 8	11 14
16	·2756	2773	2790	2807	2823	2840	2857	2874	2890	2907	3 6 8	11 14
17	·2924	2940	2957	2974	2990	3007	3024	3040	3057	3074	3 6 8	11 14
18	·3090	3107	3123	3140	3156	3173	3190	3206	3223	3239	3 6 8	11 14
19	·3256	3273	3289	3305	3322	3338	3355	3371	3387	3404	3 5 8	11 14
20	·3420	3437	3453	3469	3486	3502	3518	3535	3551	3567	3 5 8	11 14
21	·3584	3600	3616	3633	3649	3665	3681	3697	3714	3730	3 5 8	11 14
22	·3746	3762	3778	3795	3811	2827	3843	3859	3875	3891	3 5 8	11 14
23	·3907	3923	3939	3955	3971	3987	4003	4019	4035	4051	3 5 8	11 14
24	·4067	4083	4099	4115	4131	4147	4163	4179	4195	4210	3 5 8	11 13
25	·4226	4242	4258	4274	4289	4305	4321	4337	4352	4368	3 5 8	11 13
26	·4384	4399	4415	4431	4446	4462	4478	4493	4509	4524	3 5 8	10 13
27	·4540	4555	4571	4586	4602	4617	4633	4648	4664	4679	3 5 8	10 13
28	·4695	4710	4726	4741	4756	4772	4787	4802	4818	4833	3 5 8	10 13
29	·4848	4863	4879	4894	4909	4924	4939	4955	4970	4985	3 5 8	10 13
30	·5000	5015	5030	5045	5060	5075	5090	5105	5120	5135	3 5 8	10 13
31	·5150	5165	5180	5195	5210	5225	5240	5255	5270	5284	2 5 7	10 12
32	·5299	5314	5329	5344	5358	5373	5388	5402	5417	5432	2 5 7	10 12
33	·5446	5461	6476	5490	5505	5519	5534	5548	5563	5577	2 5 7	10 12
34	·5592	5606	5621	5635	5650	5664	5678	5693	5707	5721	2 5 7	10 12
35	·5736	5750	5764	5779	5793	5807	5821	5835	5850	5864	2 5 7	10 12
36	·5878	5892	5906	5920	5934	5848	5962	5976	5990	6004	2 5 7	9 12
37	·6018	6032	6046	6060	6074	6088	6101	6115	6129	6143	2 5 7	9 12
38	·6157	6170	6184	6198	6211	6225	6239	6252	6266	6280	2 5 7	9 11
39	·6293	6307	6320	6334	6347	6361	6374	6388	6401	6414	2 4 7	9 11
40	·6428	6441	6455	6468	6481	6494	6508	6521	6534	6547	2 4 7	9 11
41	·6561	6574	6587	6600	6613	6626	6639	6652	6665	6678	2 4 7	9 11
42	·6691	6704	6717	6730	6743	6756	6769	6782	6794	6807	2 4 6	9 11
43	·6820	6833	6845	6858	6871	6884	6896	6909	6921	6934	2 4 6	8 11
44	·6947	6959	6972	6984	6997	7009	7022	7034	7046	7059	2 4 6	8 10

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NATURAL SINES

Gandhi Memorial College Of Education Bantalab Jammu

Degrees	0' 0°.0	6' 0°.1	12' 0°.2	18' 0°.3	24' 0°.4	30' 0°.5	36' 0°.6	42' 0°.7	48' 0°.8	54' 0°.9	Mean Differences 1 2 3	4 5
45	·7071	7083	7096	7108	7120	7133	7145	7157	7169	7181	2 4 6	8 10
46	·7193	7206	7218	7230	7242	7254	7266	7278	7290	7302	2 4 6	8 10
47	·7314	7325	7337	7349	7361	7373	7385	7396	7408	7420	2 4 6	8 10
48	·7431	7443	7455	7466	7478	7490	7501	7513	7524	7536	2 4 6	8 10
49	·7547	7558	7570	7581	7593	7604	7615	7627	7638	7649	2 4 6	8 9
50	·7660	7672	7683	7694	7705	7716	7727	7738	7749	7760	2 4 6	7 9
51	·7771	7782	7793	7804	7815	7826	7837	7848	7859	7869	2 4 5	7 9
52	·7880	7891	7902	7912	7923	7934	7944	7955	7965	7976	2 4 5	7 9
53	·7986	7997	8007	8018	8028	8039	8049	8059	8070	8080	2 3 5	7 9
54	·8090	8100	8111	8121	8131	8141	8151	8161	8171	·81	2 3 5	7 8
55	·8192	8202	8211	8221	8231	8241	8251	8261	8271	8281	2 3 5	7 8
56	·8290	8300	8310	8320	8329	8339	8348	8358	8368	8377	2 3 5	6 8
57	·8387	8396	8406	8415	8425	8434	8443	8453	8462	8471	2 3 5	6 8
58	·8480	8490	8499	8508	8517	8526	8536	8545	8554	8563	2 3 5	6 8
59	·8572	8581	8590	8599	8607	8616	8625	8634	8643	8652	1 3 4	6 7
60	·8660	8669	8678	8686	8695	8704	8712	8721	8729	8738	1 3 4	6 7
61	·8746	8755	8763	8771	8780	8788	8796	8805	8813	8821	1 3 4	6 7
62	·8829	8838	8846	8854	8862	8870	8878	8886	8894	8902	1 3 4	5 7
63	·8910	8918	8926	8934	8942	8949	8957	8965	8973	8980	1 3 4	5 6
64	·8988	8996	9003	9011	9018	9026	9033	9041	9048	9056	1 3 4	5 6
65	·9063	9070	9078	9085	9092	9100	9107	9114	9121	9128	1 2 4	5 6
66	·9135	9143	9150	9157	9164	9171	9178	9184	9191	9198	1 2 3	5 6
67	·9205	9212	9219	9225	9232	9239	9345	9252	9259	9265	1 2 3	4 6
68	·9272	9278	9285	9291	9298	9304	9311	9317	9323	9330	1 2 3	4 5
69	·9336	9342	9348	9354	9361	9367	9373	9379	9385	9391	1 2 3	4 5
70	·9397	9403	9409	9415	9421	9426	9432	9438	9444	9449	1 2 3	4 5
71	·9455	9461	9466	9472	9478	9483	9489	9494	9500	9505	1 2 3	4 5
72	·9511	9516	9521	9527	9532	9537	9542	9548	9553	9558	1 2 3	3 4
73	·9563	9568	9573	9578	9583	9588	9593	9598	9603	9608	1 2 2	3 4
74	·9613	9617	9622	9627	9632	9636	9641	9646	9650	9655	1 2 2	3 4
75	·9659	9664	9668	9673	9677	9681	9686	9690	9694	9699	1 1 2	3 4
76	·9703	9707	9711	9715	9720	9724	9728	9732	9736	9740	1 1 2	3 3
77	·9744	9748	9751	9755	9759	9763	9767	9770	9774	9778	1 1 2	3 3
78	·9781	9785	9789	9792	9796	9799	9803	9806	9810	9813	1 1 2	2 3
79	·9816	9820	9823	9826	9829	9833	9836	9839	9842	9845	1 1 2	2 3
80	·9848	9851	9854	9857	9860	9863	9866	9869	9871	9874	0 1 1	2 2
81	·9877	9880	9882	9885	9888	9890	9893	9895	9898	9900	0 1 1	2 2
82	·9903	9905	9907	9910	9912	9914	9917	9919	9921	9923	0 1 1	2 2
83	·9925	9928	9930	9932	9934	9936	9938	9940	9942	9943	0 1 1	1 2
84	·9945	9947	9949	9951	9952	8854	9956	9957	9959	9960	0 1 1	1 2
85	·9962	9963	9965	9966	9968	9969	9971	9972	9973	9974	0 0 1	1 1
86	·9976	9977	9978	9979	9980	9981	9982	9983	9984	9985	0 0 1	1 1
87	·9986	9987	9988	9989	9990	9990	9991	9992	9993	9993	0 0 0	1 1
88	·9994	9995	9995	9996	9996	9997	9997	9997	9998	9998	0 0 0	0 0
89	·9998	9999	9999	9999	9999	1.000	1.000	1.000	1.000	1.000	0 0 0	0 0
90	1·000											

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NATURAL COSINES

[Numbers in difference columns to be subtracted, not added.]

Degrees	0' 0°.0	6' 0°.1	12' 0°.2	18' 0°.3	24' 0°.4	30' 0°.5	36' 0°.6	42' 0°.7	48' 0°.8	54' 0°.9	Mean Differences 1 2 3	Mean Differences 4 5
0	1·000	1·000	1·000	1·000	1·000	1·000	9999	9999	9999	9999	0 0 0	0 0
1	·9998	9998	9998	9997	9997	9997	9996	9996	9995	9995	0 0 0	0 0
2	·9994	9993	9993	9992	9991	9990	9990	9989	9988	9987	0 0 0	1 1
3	·9986	9985	9984	9983	9982	9981	9980	9979	9978	9977	0 0 1	1 1
4	·9976	9974	9973	9972	9971	9969	9968	9966	9965	9963	0 0 1	1 1
5	·9962	9960	9959	9957	9956	9954	9952	9951	9949	9947	0 1 1	1 2
6	·9945	9943	9942	9940	9938	9936	9934	9932	9930	9928	0 1 1	1 2
7	·9925	9923	9921	9919	9917	9914	9912	9910	9907	9905	0 1 1	2 2
8	·9903	9900	9898	9895	9893	9890	9888	9885	9882	9880	0 1 1	2 2
9	·9877	9874	9871	9869	9866	9863	9860	9857	9854	9851	0 1 1	2 2
10	·9848	9845	9842	9839	9836	9833	9829	9826	9823	9820	1 1 2	2 3
11	·9816	9813	9810	9806	9803	9799	9796	9792	9789	9785	1 1 2	2 3
12	·9781	9778	9774	9770	9767	9763	9759	9755	9751	9748	1 1 2	3 3
13	·9744	9740	9736	9732	9728	9724	9720	9715	9711	9707	1 1 2	3 3
14	·9703	9699	9694	9690	9686	9681	9677	9673	9668	9664	1 1 2	3 4
15	·9659	9655	9650	9646	9641	9636	9632	9627	9622	9617	1 2 2	3 4
16	·9613	9608	9603	9598	9593	9588	9583	9578	9573	9568	1 2 2	3 4
17	·9563	9558	9553	9548	9542	9537	9532	9527	9521	9516	1 2 3	3 4
18	·9511	9505	9500	9494	9489	9483	9478	9472	9466	9461	1 2 3	4 5
19	·9455	9449	9444	9438	9432	9426	9421	9415	9409	9403	1 2 3	4 5
20	·9397	9391	9385	9379	9373	9367	9361	9354	9348	9342	1 2 3	4 5
21	·9336	9330	9323	9317	9311	9304	9298	9291	9285	9278	1 2 3	4 5
22	·9272	9265	9259	9252	9245	9239	9232	9225	9219	9212	1 2 3	4 6
23	·9205	9198	9191	9184	9178	9171	9164	9157	9150	9143	1 2 3	5 6
24	·9135	9128	9121	9114	9107	9100	9092	9085	9078	9070	1 2 4	5 6
25	·9063	9056	9048	9041	9033	9026	9018	9011	9003	8996	1 3 4	5 6
26	·8988	8980	8973	8965	8957	8949	8942	8934	8926	8918	1 3 4	5 6
27	·8910	8902	8894	8886	8878	8870	8862	8854	8846	8838	1 3 4	5 7
28	·8829	8821	8813	8805	8796	8788	8780	8771	8763	8755	1 3 4	6 7
29	·8746	8738	8729	8721	8712	8704	8695	8686	8678	8669	1 3 4	6 7
30	·8660	8652	8643	8634	8625	8616	8607	8599	8590	8581	1 3 4	6 7
31	·8572	8563	8554	8545	8536	8526	8517	8508	8499	8490	2 3 5	6 8
32	·8480	8471	8462	8453	8443	8434	8425	8415	8406	8396	2 3 5	6 8
33	·8387	8377	8368	8358	8348	8339	8329	8320	8310	8300	2 3 5	6 8
34	·8290	8281	8271	8261	8251	8241	8231	8221	8211	8202	2 3 5	7 8
35	·8192	8181	8171	8161	8151	8141	8131	8121	8111	8100	2 3 5	7 8
36	·8090	8080	8070	8059	8049	8039	8028	8018	8007	7997	2 3 5	7 9
37	·7986	7976	7965	7955	7944	7934	7923	7912	7902	7891	2 4 5	7 9
38	·7880	7869	7859	7848	7837	7826	7815	7804	7793	7782	2 4 5	7 9
39	·7771	7760	7749	7738	7727	7716	7705	7694	7683	7672	2 4 6	7 9
40	·7660	7649	7638	7627	7615	7604	7593	7581	7570	7559	2 4 6	8 9
41	·7547	7536	7524	7513	7501	7490	7478	7466	7455	7443	2 4 6	8 10
42	·7431	7420	7408	7396	7385	7373	7361	7349	7337	7325	2 4 6	8 10
43	·7314	7302	7290	7278	7266	7254	7242	7230	7218	7206	2 4 6	8 10
44	·7193	7181	7169	7157	7145	7133	7120	7108	7096	7083	2 4 6	8 10

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NATURAL COSINES

Gandhi Memorial College Of Education Bantalab Jammu

[Numbers in difference columns to be subtracted, not added.]

Degrees	0' 0°.0	6' 0°.1	12' 0°.2	18' 0°.3	24' 0°.4	30' 0°.5	36' 0°.6	42' 0°.7	48' 0°.8	54' 0°.9	Mean Differences 1 2 3	Mean Differences 4 5
45	·7071	7059	7046	7034	7022	7009	6997	6984	6972	6959	2 4 6	8 10
46	6947	6934	6921	6909	6896	6884	6871	6858	6845	6833	2 4 6	8 11
47	·6820	6807	6794	6782	6769	6756	6743	6730	6717	6704	2 4 6	9 11
48	·6691	6678	6665	6652	6639	6626	6613	6600	6587	6574	2 4 7	9 11
49	·6561	6547	6534	6521	6508	6494	6481	6468	6455	6441	2 4 7	9 11
50	·6428	6414	6401	6388	6374	6361	6347	6334	6320	6307	2 4 7	9 11
51	·6293	6280	6266	6252	6239	6225	6211	6198	6184	6170	2 5 7	9 11
52	·6157	6143	6129	6115	6101	6088	6074	6060	6046	6032	2 5 7	9 12
53	·6018	6004	5990	5976	5962	5948	5934	5920	5906	5892	2 5 7	9 12
54	·5878	5864	5850	5835	5821	5807	5793	5779	5764	5750	2 5 7	9 12
55	·5736	5721	5707	5693	5678	5664	5650	5635	5621	5606	2 5 7	10 12
56	·5592	5577	5563	5548	5534	5519	5505	5490	5476	5461	2 5 7	10 12
57	·5446	5432	5417	5402	5388	5373	5358	5344	5329	5314	2 5 7	10 12
58	·5299	5284	5270	5255	5240	5225	5210	5195	5180	5165	2 5 7	10 12
59	·5150	5135	5120	5105	5090	5075	5060	5045	5030	5015	3 5 8	10 13
60	·5000	4985	4970	4955	4939	4924	4900	4894	4879	4863	3 5 8	10 13
61	·4848	4833	4818	4802	4787	4772	4756	4741	4726	4710	3 5 8	10 13
62	·4695	4679	4664	4648	4633	4617	4602	4586	4571	4555	3 5 8	10 13
63	·4540	4524	4509	4493	4478	4462	4446	4431	4415	4399	3 5 8	10 13
64	·4384	4368	4352	4337	4321	4305	4289	4274	4258	4242	3 5 8	11 13
65	·4226	4210	4195	4179	4163	4147	4131	4115	4099	4083	3 5 8	11 13
66	·4067	4051	4035	4019	4003	3987	3971	3955	3939	3923	3 5 8	11 14
67	·3907	3891	3875	3859	3843	3827	3811	3795	3778	3762	3 5 8	11 14
68	·3746	3730	3714	3697	3681	3665	3649	3633	3616	3600	3 5 8	11 14
69	·3584	3567	3551	3535	3518	3502	3486	3469	3453	3437	3 5 8	11 14
70	·3420	3404	3387	3371	3355	3338	3322	3305	3289	3272	3 5 8	11 14
71	·3256	3239	3223	3206	3190	3173	3156	3140	3123	3107	3 6 8	11 14
72	·3090	3074	3057	3040	3024	3007	2990	2974	2957	2940	3 6 8	11 14
73	·2924	2907	2890	2874	2857	2840	2823	2807	2790	2773	3 6 8	11 14
74	·2756	2740	2723	2706	2689	2672	2656	2639	2622	2605	3 6 8	11 14
75	·2588	2571	2554	2538	2521	2504	2487	2470	2453	2436	3 6 8	11 14
76	·2419	2402	2385	2368	2351	2334	2317	2300	2284	2267	3 6 8	11 14
77	·2250	2233	2215	2198	2181	2164	2147	2130	2113	2096	3 6 9	11 14
78	·2079	2062	2045	2028	2011	1994	1977	1959	1942	1925	3 6 9	11 14
79	·1908	1891	1874	1857	1840	1822	1805	1788	1771	1754	3 6 9	11 14
80	·1736	1719	1702	1685	1668	1650	1633	1616	1599	1582	3 6 9	12 14
81	·1564	1547	1530	1513	1495	1478	1461	1444	1426	1409	3 6 9	12 14
82	·1392	1374	1357	1340	1323	1305	1288	1271	1253	1236	3 6 9	12 14
83	·1219	1201	1184	1167	1149	1132	1115	1097	1080	1063	3 6 9	12 14
84	·1045	1028	1011	0993	0976	0958	0941	0924	0906	0889	3 6 9	12 14
85	·0872	0854	0837	0819	0802	0785	0767	0750	0732	0715	3 6 9	12 15
86	0698	0680	0663	0645	0628	0610	0593	0576	0558	0541	3 6 9	12 15
87	·0523	0506	0488	0471	0454	0436	0419	0401	0384	0366	3 6 9	12 15
88	·0349	0332	0314	0297	0279	0262	0244	0227	0209	0192	3 6 9	12 15
89	·0175	0157	0140	0122	0105	0087	0070	0052	0035	0017	3 6 9	12 15
90	·0000											

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NATURAL TANGENTS

Degrees	0' 0°.0	6' 0°.1	12' 0°.2	18' 0°.3	24' 0°.4	30' 0°.5	36' 0°.6	42' 0°.7	48' 0°.8	54' 0°.9	Mean Differences 1 2 3	Mean Differences 4 5
0	·0000	0017	0035	0052	0070	0087	0105	0122	0140	0157	3 6 9	12 15
1	·0175	0192	0209	0227	0244	0262	0279	0297	0314	0332	3 6 9	12 15
2	·0349	0367	0384	0402	0419	0437	0454	0472	0489	0507	3 6 9	12 15
3	·0524	0542	0559	0577	0594	0612	0629	0647	0664	0682	3 6 9	12 15
4	·0699	0717	0734	0752	0769	0787	0805	0822	0840	0857	3 6 9	12 15
5	·0875	0892	0910	0928	0945	0963	0981	0998	1016	1033	3 6 9	12 15
6	·1051	1069	1086	1104	1122	1139	1157	1175	1192	1210	3 6 9	12 15
7	·1228	1246	1263	1281	1299	1317	1334	1352	1370	1388	3 6 9	12 15
8	·1405	1423	144	1459	1477	1495	1512	1530	1548	1566	3 6 9	12 15
9	·1584	1602	1620	1638	1655	1673	1691	1709	1727	1745	3 6 9	12 15
10	·1763	1781	1799	1817	1835	1853	1871	1890	1908	1926	3 6 9	12 15
11	·1944	1962	1980	1998	2016	2035	2053	2071	2089	2107	3 6 9	12 15
12	·2126	2144	2162	2180	2199	2217	2235	2254	2272	2290	3 6 9	12 15
13	·2309	2327	2345	2364	2382	2401	2419	2438	2456	2475	3 6 9	12 15
14	·2493	2512	2530	2549	2568	2586	2605	2623	2642	2661	3 6 9	12 16
15	·2679	2698	2717	2736	2754	2773	2792	2811	2830	2849	3 6 9	13 16
16	·2867	2886	2905	2924	2943	2962	2981	3000	3019	3038	3 6 9	13 16
17	·3057	3076	3096	3115	3134	3153	3172	3191	3211	3230	3 6 10	13 16
18	·3249	3269	3288	3307	3327	3346	3365	3385	3404	3424	3 6 10	13 16
19	·3443	3463	3482	3502	3522	3541	3561	3581	3600	3620	3 7 10	13 16
20	·3640	3659	3679	3699	3719	3739	3759	3779	3799	3819	3 7 10	13 17
21	·3839	3859	3879	3899	3919	3939	3959	3979	4000	4020	3 7 10	13 17
22	·4040	4061	4081	4101	4122	4142	4163	4183	4204	4224	3 7 10	14 17
23	·4245	4265	4286	4307	4327	4348	4369	4390	4411	4431	3 7 10	14 17
24	·4452	4473	4494	4515	4536	4557	4578	4599	4621	4642	4 7 11	14 18
25	·4663	4684	4706	4727	4748	4770	4791	4813	4834	4856	4 7 11	14 18
26	·4877	4899	4921	4942	4964	4986	5008	5029	5051	5073	4 7 11	15 18
27	·5095	5117	5139	5161	5184	5206	5228	5250	5272	5295	4 7 11	15 18
28	·5317	5340	5362	5384	5407	5430	5452	5475	5498	5520	4 8 11	15 19
29	·5543	5566	5589	5612	5635	5658	5681	5704	5727	5750	4 8 12	15 19
30	·5774	5797	5820	5844	5867	5890	5914	5938	5961	5985	4 8 12	16 20
31	·6009	6032	6056	6080	6104	6128	6152	6176	6200	6224	4 8 12	16 20
32	·6249	6273	6297	6322	6346	6371	6395	6420	6445	6469	4 8 12	16 20
33	·6494	6519	6544	6569	6594	6619	6644	6669	6694	6720	4 8 13	17 21
34	·6745	6771	6796	6822	6847	6873	6899	6924	6950	6976	4 9 13	17 21
35	·7002	7028	7054	7080	7107	7133	7159	7186	7212	7239	4 9 13	18 22
36	·7265	7292	7319	7346	7373	7400	7427	7454	7481	7508	5 9 14	18 23
37	·7536	7563	7590	7618	7646	7673	7701	7729	7757	7785	5 9 14	18 23
38	·7813	7841	7869	7898	7926	7954	7983	8012	8040	8069	5 9 14	19 24
39	·8098	8127	8156	8185	8214	8243	8273	8302	8332	8361	5 10 15	20 24
40	·8391	8421	8451	8481	8511	8541	8571	8601	8632	8662	5 10 15	20 25
41	·8693	8724	8754	8785	8816	8847	8878	8910	8941	8972	5 10 16	21 26
42	·9004	9036	9067	9099	9131	9163	9195	9228	9260	9293	5 11 16	21 27
43	·9325	9358	9391	9424	9457	9490	9523	9556	9590	9623	6 11 17	22 28
44	·9657	9691	9725	9759	9793	9827	9861	9896	9930	9965	6 11 17	23 29

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Degrees	0' 0".0	6' 0".1	12' 0".2	18' 0".3	24' 0".4	30' 0".5	36' 0".6	42' 0".7	48' 0".8	54' 0".9	Mean Differences 1 2 3	4 5
45	1·0000	0035	0070	0105	0141	0176	0212	0247	0283	0319	6 12 18	24 30
46	1·0355	0392	0428	0464	0501	0538	0575	0612	0649	0686	6 12 18	25 31
47	1·0724	0761	0799	0837	0875	0913	0951	0990	1028	1067	6 13 19	25 32
48	1·1106	1145	1184	1224	1263	1303	1343	1383	1423	1463	7 13 20	27 33
49	1·1504	1544	1585	1626	1667	1708	1750	1792	1833	1875	7 14 21	28 34
50	1·1918	1960	2002	2045	2088	2131	2174	2218	2261	2305	7 14 22	29 36
51	1·2349	2393	2437	2482	2527	2572	2617	2662	2708	2753	8 15 23	30 38
52	1·2799	2846	2892	2938	2985	3032	3079	3127	3175	3222	8 16 24	31 39
53	1·3270	3319	3367	3416	3465	3514	3564	3613	3663	3713	8 16 25	33 41
54	1·3764	3814	3865	3916	3968	4019	4071	4124	4176	4229	9 17 26	34 43
55	1·4281	4335	4388	4442	4496	4550	4605	4659	4715	4770	9 18 27	36 45
56	1·4826	4882	4938	4994	5051	5108	5166	5224	5282	5340	10 19 29	38 48
57	1·5399	5458	5517	5577	5637	5697	5757	5818	5830	5941	10 20 30	40 50
58	1·6003	6066	6128	6191	6255	6319	6383	6447	6512	6577	11 21 32	43 53
59	1·6643	6709	6775	6842	6909	6977	7045	7113	7182	7251	11 23 34	45 56
60	1·7321	7391	7461	7532	7603	7675	7747	7820	7893	7966	12 24 36	48 60
61	1·8040	8115	8190	8265	8341	8418	8495	8572	8650	8728	13 26 38	51 64
62	1·8807	8887	8967	9047	9128	9210	9292	9375	9458	9542	14 27 41	55 68
63	1·9626	9711	9797	9883	9970	2·0057	2·0145	2·0233	2·0323	2·0413	15 29 44	58 73
64	2·0503	0594	0686	0778	0872	0965	1060	1155	1251	1348	16 31 47	63 78
65	2·1445	1543	1642	1742	1842	1943	2045	2148	2251	2355	17 34 51	68 85
66	2·2460	2566	2673	2781	2889	2998	3109	3220	3332	3445	18 37 55	73 92
67	2·3559	3673	3789	3906	4023	4142	4262	4383	4504	4627	20 40 60	79 99
68	2·4751	4876	5002	5129	5257	5386	5517	5649	5782	5916	22 43 65	87 108
69	2·6051	6187	6325	6464	6605	6746	6889	7034	7179	7326	24 47 71	95 119
70	2·7475	7625	7776	7929	8083	8239	8397	8556	8716	8878	26 52 78	104 131
71	2·9042	9208	9375	9544	9714	9887	3·0061	3·0237	3·0415	3·0595	29 58 87	116 145
72	3·0777	0961	1146	1334	1524	1716	1910	2106	2305	2506	32 64 96	129 161
73	3·2709	2914	3122	3332	3544	3759	3977	4197	4420	4646	36 72 108	144 180
74	3·4874	5105	5339	5576	5816	6059	6305	6554	6806	7062	41 81 122	163 204
75	3·7321	7583	7848	8118	8391	8667	8947	9232	9520	9812	46 93 139	186 232
76	4·0108	0408	0713	1022	1335	1653	1976	2303	2635	2972	53 107 160	213 267
77	4·3315	3662	4015	4374	4737	5107	5483	5864	6252	6646		
78	4·7046	7453	7867	8288	8716	9152	9594	5·0045	5·0504	5·0970	Mean differences cease to be sufficiently accurate.	
79	5·1446	1929	2422	2924	3435	3955	4486	5026	5578	6140		
80	5·6713	7297	7894	8502	9124	9758	6·0405	6·1066	6·1742	6·2432		
81	6·3138	3859	4596	5350	6122	6912	7720	8548	9395	7·0264		
82	7·1154	2066	3002	3962	4947	5958	6996	8062	9158	8·0285		
83	8·1443	2636	3863	5126	6427	7769	9152	9·0579	9·2052	9·3572		
84	9·5144	9·677	9·845	10·02	10·20	10·39	10·58	10·78	10·99	11·20		
85	11·43	11·66	11·91	12·16	12·43	12·71	13·00	13·30	13·62	13·95		
86	14·30	14·67	15·06	15·46	15·89	16·35	16.83	17·34	17·89	18·46		
87	19·08	19·74	20·45	21·20	22·02	22·90	23.86	24·90	26·03	27·27		
88	28·64	30·14	31·82	33·69	35·80	38·19	40.92	44·07	47·74	52·08		
89	57·29	63·66	71·62	81·85	95·49	114·5	143.2	191·0	286·5	573·0		
90	∞											

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POWERS, ROOTS AND RECIPROCALS

n	n^2	n^3	$\sqrt{n}$	$\sqrt[3]{n}$	$\sqrt{10n}$	$\sqrt[3]{10n}$	$\sqrt[3]{100n}$	$\frac{1}{n}$
1	1	1	1	1	3·162	2·154	4·642	1
2	4	8	1·414	1·260	4·472	2·714	5·848	·5000
3	9	27	1·732	1·442	5·477	3·107	6·694	·3333
4	16	64	2	1·587	6·325	3·420	7·368	·2500
5	25	125	2·236	1·710	7·071	3·684	7·937	·2000
6	36	216	2·449	1·817	7·746	3·915	8·434	·1667
7	49	343	2·646	1·913	8·367	4·121	8·879	·1429
8	64	512	2·828	2·000	8·944	4·309	9·283	·1250
9	81	729	3·000	2·080	9·487	4·481	9·655	·1111
10	100	1000	3·162	2·154	10·0	4·642	10·000	·1000
11	121	1331	3·317	2·224	10·488	4·791	10·323	·09091
12	144	1728	3·464	2·289	10·994	4·932	10·627	·08333
13	169	2197	3·606	2·351	11·402	5·066	10·914	·07692
14	196	2744	3·742	2·410	11·852	5·192	11·187	·07143
15	225	3375	3·873	2·466	12·247	5·313	11·447	·06667
16	256	4096	4·000	2·520	12·649	5·429	11·696	·06250
17	289	4913	4·123	2·571	13·038	5·540	11·935	·05882
18	324	5832	4·243	2·621	13·416	5·646	12·164	·05556
19	361	6859	4·359	2·668	13·784	5·749	12·386	·05263
20	400	8000	4·472	2·714	14·142	5·848	12·599	·0500
21	441	9261	4·583	2·759	14·491	5·944	12·806	·04762
22	484	10648	4·690	2·802	14·832	6·037	13·006	·04545
23	529	12167	4·796	2·844	15·166	6·127	13·200	·04348
24	576	13824	4·899	2·884	15·492	6·214	13·389	·04167
25	625	15625	5·000	2·924	15·811	6·300	13·572	·0400
26	676	17576	5·099	2·952	16·125	6·383	13·751	·03846
27	729	19683	5·196	3·000	16·432	6·463	13·925	·03704
28	784	21952	5·292	3·037	16·733	6·542	14·095	·03571
29	841	24389	5·385	3·072	17·029	6·619	14·260	·03448
30	900	27000	5·477	3·107	17·321	6·694	14·422	·03333
31	961	29791	5·568	3·141	17·607	6·758	14·581	·03226
32	1024	32768	5·657	3·175	17·889	6·840	14·736	·03125
33	1089	35937	5·745	3·208	18·166	6·910	14·888	·03030
34	1156	39304	5·831	3·240	18·439	6·980	15·037	·02941
35	1225	42875	5·916	3·271	18·708	7·047	15·183	·02857
36	1296	46656	6·000	3·302	18·974	7·114	15·326	·02778
37	1369	50653	6·083	3·332	19·235	7·179	15·467	·02703
38	1444	54872	6·164	3·362	19·494	7·243	15·605	·02632
39	1521	59319	6·245	3·391	19·748	7·306	15·741	·02564
40	1600	64000	6·325	3·420	20·00	7·368	15·874	·0250
41	1681	68921	6·403	3·448	20·248	7·429	16·005	·02439
42	1764	74088	6·481	3·476	20·494	7·489	16·134	·02381
43	1849	79507	6·577	3·503	20·736	7·548	16·261	·02326
44	1936	85184	6·633	3·530	20·976	7·606	16·386	·02273
45	2025	91125	6·708	3·557	21·213	7·663	16·510	·02222
46	2116	97336	6·782	3·583	21·448	7·719	16·631	·02174
47	2209	103823	6·856	3·609	21·679	7·775	16·751	·02128
48	2304	110592	6·928	3·634	21·909	7·830	16·869	·02083
49	2401	117649	7·000	3·659	22·136	7·884	16·985	·02041
50	2500	125000	7·071	3·684	23·361	7·937	17·100	·020

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n	n^2	n^3	$\sqrt{n}$	$\sqrt[3]{n}$	$\sqrt{10n}$	$\sqrt[3]{10n}$	$\sqrt[3]{100n}$	$\frac{1}{n}$
51	2601	132651	7·141	3·708	22·583	7·900	17·213	·01961
52	2704	140608	7·211	3·733	22·804	8·041	17·325	·01923
53	2809	148877	7·280	3·756	23·022	8·093	17·435	·01887
54	2916	157464	7·348	3·780	23·238	8·143	17·544	·01852
55	3025	166375	7·416	3·803	23·452	8·193	17·652	·01818
56	3136	175616	7·483	3·826	23·664	8·243	17·758	·01786
57	3249	185193	7·550	3·849	23·875	8·291	17·863	·01754
58	3364	195112	7·616	3·871	24·083	8·340	17·967	·01724
59	3481	205379	7·681	3·893	24·290	8·387	18·070	·01695
60	3000	216000	7·746	3·915	24·495	8·434	18·171	·01667
61	3721	226981	7·810	3·936	24·698	8·481	18·272	·01639
62	3844	238328	7·874	3·958	24·900	8·527	18·371	·01613
63	3969	250047	7·937	3·979	25·100	8·573	18·469	·01587
64	4096	262144	8·000	4·000	25·298	8·618	18·566	·01562
65	4225	274625	8·062	4·021	25·495	8·662	18·663	·01538
66	4356	287496	8·124	4·041	25·690	8·707	18·758	·01515
67	4489	300763	8·185	4·062	25·884	8·750	18·852	·01493
68	4624	314432	8·246	4·082	26·077	8·794	18·945	·01471
69	4761	328509	8·307	4·102	26·268	8·837	19·038	·01449
70	4900	343000	8·367	4·121	26·458	8·879	19·129	·01429
71	5041	357911	8·426	4·141	26·646	8·921	19·220	·01408
72	5184	373248	8·485	4·160	26·833	8·963	19·310	·01389
73	5329	389017	8·544	4·179	27·019	9·004	19·399	·01370
74	5476	405224	8·602	4·198	27·203	9·045	19·487	·01351
75	5625	421825	8·660	4·217	27·386	0·086	19·574	·01333
76	5776	438976	8·718	4·236	27·568	9·126	19·661	·01316
77	5929	456533	8·775	4·254	27·749	9·166	19·747	·01299
78	6084	474552	8·832	4·273	27·928	9·205	19·832	·01282
79	6241	493039	8·888	4·291	28·107	9·244	19·916	·01266
80	6400	512000	8·944	4·309	28·284	9·283	20·000	·01250
81	6561	531441	9·000	4·327	28·460	9·322	20·083	·01235
82	6724	551368	9·055	4·344	28·646	9·360	20·165	·01220
83	6889	571787	9·110	4·362	28·810	9·398	20·247	·01205
84	7056	592704	9·165	4·380	28·983	9·435	20·328	·01190
85	7225	614125	9·220	4·397	29·155	9·473	20·408	·01176
86	7396	636036	9·274	4·414	29·326	9·510	20·488	·01163
87	7569	658503	9·327	4·431	29·496	9·546	20·567	·01149
88	7744	681472	9·381	4·448	29·665	9·583	20·646	·01136
89	7921	704969	9·434	4·465	29·833	9·619	20·724	·01124
90	8100	729000	9·487	4·481	30·000	9·655	20·801	·01111
91	8281	753571	9·539	4·498	30·166	9·691	20·878	·01099
92	8464	778688	9·592	4·514	30·332	9·726	20·954	·01087
93	8649	804357	9·644	4·531	30·496	9·761	21·029	·01075
94	8836	830584	9·695	4·547	30·659	9·796	21·105	·01064
95	9025	857375	9·747	4·563	30·822	9·830	21·179	·01053
96	9216	884736	9·798	4·579	30·984	9·865	21·253	·01042
97	9409	912673	9·849	4·595	31·145	9·899	21·327	·01031
98	9604	941192	9·899	4·610	31·305	9·933	21·400	·01020
99	9801	970299	9·950	4·626	31·464	9·967	21·472	·01010
100	10000	1000000	10·000	4·642	31·623	10·000	21·544	·0100

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